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THESIS

A MODEL FOR EFFECTIVE SYSTEMS ENGINEERING WORKFORCE DEVELOPMENT AT SPACE AND NAVAL WARFARE SYSTEMS CENTER (SSC) ATLANTIC

by

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September 2013

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13. ABSTRACT (maximum 200 words)

This thesis describes a methodology used to develop a systems engineering (SE) competency framework for Space and Naval Warfare Systems Center (SSC) Atlantic—a Department of Navy organization whose vision statement is to "Make IT count for the Warfighter and the Nation." This methodology defines the role of systems engineers at SSC Atlantic; establishes prioritized SE competency areas; identifies associated knowledge, skills and abilities (KSAs); identifies optimal workforce development methods for each KSA; and addresses how to assess systems engineers against a competency development model.

The results of this analysis show that systems engineers require many of the same KSAs as other members of the engineering workforce, but also require unique KSAs focused on customer mission/capability areas, technology areas, SE processes/activities and leadership skills. Developmental methods for systems engineers to obtain these KSAs range from informal on-the-job training to professional certifications and degrees. The methodology established in this thesis can be used by other organizations to develop and employ their own competency framework in practically any discipline. The SE competency framework defined in this thesis can be leveraged/tailored by other SE organizations in order to establish developmental roadmaps for improving the KSAs of their workforce.

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A MODEL FOR EFFECTIVE SYSTEMS ENGINEERING WORKFORCE DEVELOPMENT AT SPACE AND NAVAL WARFARE SYSTEMS CENTER (SSC) ATLANTIC

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LIST OF ACRONYMS AND ABBREVIATIONS

APPEL	Academy of Program/Project & Engineering Leadership
CSEP	Certified Systems Engineering Professional
CL/PO	Continuous Learning/Performance Objective
CDM	Competency Development Model
DAG	Defense Acquisition Guidebook
DAU	Defense Acquisition University
DAWIA	Defense Acquisition Workforce Improvement Act
DON	Department of Navy
GRCSE	Graduate Reference Curriculum for Systems Engineering
IA	Information Assurance
IEEE	Institute of Electrical and Electronics Engineers
IPT	Integrated Product Team
INCOSE	International Council on Systems Engineering
KSAs	Knowledge, Skills, and Abilities
MCLP	Mid-Career Leadership Program
NASA	National Aeronautics and Space Administration
NCWF	National Cybersecurity Workforce Framework
NIST	National Institute of Standards and Technology
NPS	Naval Postgraduate School
NUWC	Naval Undersea Warfare Center
OPM	Office of Personnel Management
OJT	On-the-job
PSE	Program Systems Engineering
PLC	Project Life Cycle
PMI	Project Management Institute
RF	Radio Frequency
SFIA	Skills Framework for the Information Age
SPAWAR	Space and Naval Warfare
SSC	Space and Naval Warfare Systems Center

SE	Systems Engineering
SEBoK	Systems Engineering Body of Knowledge
SoS	Systems of Systems
SoSE	Systems of Systems Engineering
SPRDE	Systems Planning, Research, Development & Engineering
TWMS	Total Workforce Management Services

EXECUTIVE SUMMARY

This thesis examines how to build and employ a framework for developing the competency of systems engineers at a Department of Defense (DoD) organization such as Space and Naval Warfare Systems Center (SSC) Atlantic. While there are many high-level government and industry models for systems engineering (SE) competency development, few provide a comprehensive, prioritized set of knowledge, skills and abilities (KSAs), recommendations on how to actually develop systems engineers and insight into how systems engineering competency might be assessed. Furthermore, there is little understanding of the various types of systems engineers at an information technology-centric DoD organization and how their skillsets may need to differ. This thesis examines the various types of systems engineering competency areas and associated KSAs defined by Defense Acquisition University (DAU), National Aeronautics and Space Administration, International Council on Systems Engineering and Naval systems engineering competency models. It also examines those competency and KSA areas that are of particular importance to SSC Atlantic, such as those defined by the National Institute of Standards and Technology in the National Cybersecurity Workforce Framework. This paper analyzes various forms of education and training that can be used to support the development of systems engineering KSAs and when they are most appropriate.

The results of this thesis show that, in order to properly develop a SE workforce in an IT command such as SSC Atlantic, one must first understand *what* competency areas and KSAs systems engineers must attain. A SE competency framework should consider the SE life cycle processes, and also technology areas, mission/capability areas and leadership skills to ensure that systems engineers are well rounded in order to provide technical leadership to multi-disciplinary teams with role-diverse team members. When establishing a competency framework, careful consideration should be made toward which precise use case(s) will be supported by the framework. Identifying relevant and authoritative competency area and KSA sources for the competency framework is also critical, as there is no need to recreate data that has already been adequately developed by

several other relevant and established industry and DoD organizations. When prioritizing competency areas and KSAs, each SE use case must be considered separately as each will likely emphasize different competency areas. Competency areas such as stakeholder requirements definition, requirements analysis, architecture design, software engineering, acquisition, verification and system assurance require more emphasis at SSC Atlantic than others. In order to establish systems engineering roles that can be well understood across the organization, one must examine the roles that will interact with the role of a systems engineer in order to determine where KSAs will be shared across the roles or unique to one or the other.

Analysis must also be conducted to understand *how* these KSAs can and should be obtained. The most common methods for developing SE KSAs are through educational training (DAU, degrees or certifications), in-house-developed training courses/workshops, and on-the-job training (OJT). DAU Systems Planning, Research, Development & Engineering—SE classes can be effective when providing systems engineers with basic knowledge and comprehension of the SE life cycle processes—particularly in the areas of acquisition and risk management. Leadership skills can be developed through programs, such as the Mid-Career Leadership and Mentorship Programs. OJT can be enhanced when coupled with targeted rotational and job shadowing opportunities. If approached systematically, immeasurable value can be obtained from developing in-house SE training that engages systems engineers at all levels of the workforce. The Graduate Reference Curriculum for Systems Engineering provides useful, tailorable recommendations on how to develop and assess SE curricula. When it comes to assessing the competency of systems engineers, care must be taken to choose an assessment process and associated assessment methodologies that are relatively thorough yet not overly cumbersome, time-consuming and costly.

This thesis goes through the process of establishing a SE competency framework for SSC Atlantic that can easily be tailored for other SE-focused organizations. The process begins by defining the role(s) of systems engineers within the organization. Then existing competency frameworks are examined in order leverage existing best practices.

Competency areas (or KSA groupings) are examined and prioritized based on how systems engineering should be conducted in the most likely project use cases.

Once the basic requirements for the competency framework are established, then a competency framework is built to address a complete set of competency areas and KSAs desired for systems engineers within an organization. Alternative methods are defined for developing competency. Criteria are established to determine optimal methods for developing different types of KSAs. This allows for each systems engineer KSA to be mapped to optimal development methods. Finally, a manner for assessing systems engineers is developed and executed in order to track each systems engineer's progression in terms of proficiency.

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I. INTRODUCTION

A. BACKGROUND

Since the inception of the field of systems engineering, corporations and government organizations worldwide have been trying to figure out what knowledge, skills and abilities (KSAs) are most crucial for practicing systems engineers. Competency models, such as the systems planning, research, development and engineering—systems engineering/program systems engineering (SPRDE-SE/PSE) competency model developed by Defense Acquisition University (DAU) and the project management and systems engineering competency framework developed by the National Aeronautics and Space Administration (NASA) help frame what KSAs are most needed in order to effectively perform systems engineering (see NASA, 2012 and DAU SPRDE-SE/PSE Competency Model, 2009). As the systems being engineered continue to evolve and become more complex, some competency models, such as the International Council on Systems Engineering (INCOSE) systems engineering competency framework have also evolved in order to address system complexity throughout the systems engineering life cycle (International Council on Systems Engineering [INCOSE], 2010).

Today the challenge does not lie as much in developing or adopting a competency model for an organization tasked with delivering complex systems, as there are many overarching and industry-standard models from which to choose. Rather, the greater challenge is figuring out how to tailor and employ existing competency models in order to develop individuals' KSAs in an effective and cost-efficient manner. In other words, how do we know which competency areas and KSAs are most critically needed to perform systems engineering? What are the variables in systems engineering that drive the importance of the various systems engineering (SE) competency areas? What methods should be employed to develop KSAs in systems engineers—on-the-job training (OJT), in-house classroom training, vendor-provided training, undergraduate or graduate programs, etc.? Under what circumstances is each method most appropriate?

B. PURPOSE

The purpose of this thesis is to understand what type of competency framework Space and Naval Warfare Systems Center (SSC) Atlantic should employ in order to develop its systems engineers. This will be achieved by synthesizing together elements from industry and government-standard competency models that have been generated by organizations external to SSC Atlantic. This will also include drawing from legacy competency models employed by SSC Atlantic over the last five years. This thesis aims to determine what types of education and training (structured and unstructured) can best be used to maximize the effectiveness of systems engineers.

More specifically, this thesis will examine various types of systems engineering competency areas and associated KSAs defined by DAU, NASA, and INCOSE competency models. This thesis will also look closely at the Naval Systems Engineering (SE) Competency Development Model (CDM), which itself is tailored from a strong pedigree of various organizations' SE competency frameworks—those of NASA, DAU and INCOSE, but also of Boeing and the Naval Underwater Warfare Center, Newport. This thesis will also examine those competency and KSA areas that are of particular importance to SSC Atlantic, such as those defined by the National Institute of Standards and Technology (NIST) in the national cybersecurity workforce framework (NCWF). The Graduate Reference Curriculum for Systems Engineering (GRCSE) will also be examined to determine how it can be applied in order to employ a newly-tailored SSC Atlantic SE CDM.

C. RESEARCH QUESTIONS

1. What competency areas and associated KSAs are particularly applicable to SSC Atlantic systems engineers?
2. How can the GRCSE be used to effectively employ a CDM?
3. How do various forms of education and training best support the development of KSAs required to develop competent systems engineers at SSC Atlantic?

D. BENEFITS OF STUDY

This thesis is intended to provide recommendations to the leadership of Department of Defense (DoD) IT organizations on how to best approach competency development and the delivery of systems engineering education, training and other forms of developmental opportunities to their engineering workforce. More specifically, the Space and Naval Warfare Command (SPAWAR) and its systems centers—SSC Atlantic and SSC Pacific—as well as similar organizations should benefit from these analyses and recommendations. These recommendations will be used to shape future SE course learning objectives and competency development models employed by SPAWAR. The recommendations should assist in making better decisions on where to spend workforce development training funds in an increasingly budget-constrained DoD environment. This thesis will also provide an approach toward *tailoring* and *employing* competency development models for a DoD organization whose primary mission is to deliver complex IT solutions to a diverse base of end users.

E. SCOPE AND METHODOLOGY

This thesis seeks to develop a competency framework that can be directly used by SSC Atlantic to develop various types of systems engineers. This framework defines how CDMs are structured and employed in terms such as competency vectors and competency areas. Each individual CDM within the framework is based upon different systems engineering use cases and will define the associated KSAs categorized by competency stages, or levels. The methodology depicted in Figure 1 is employed in order to develop this overarching SE competency framework.

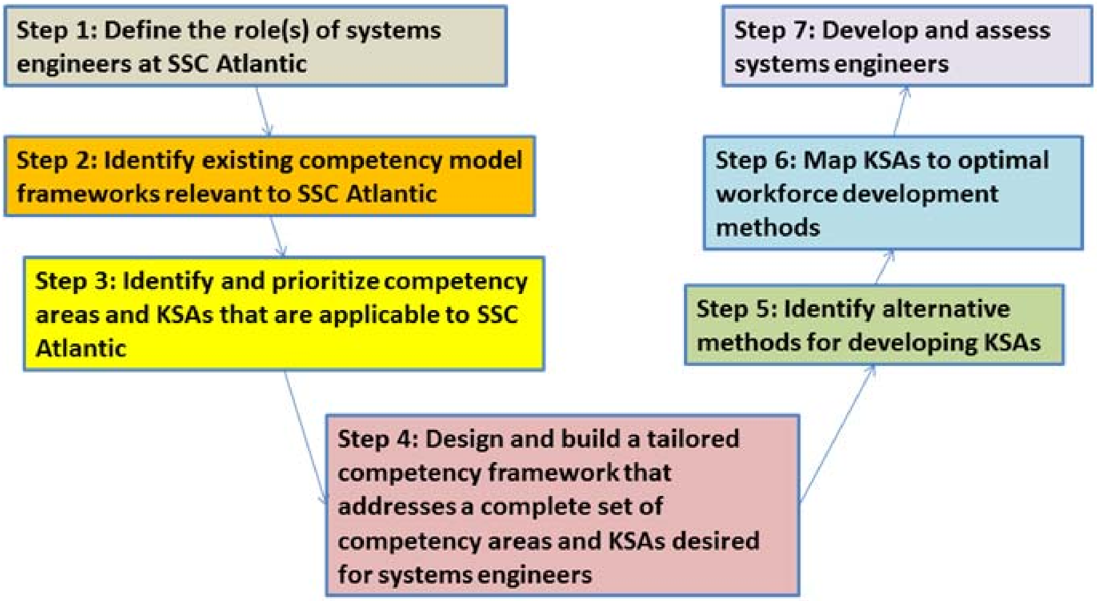

Figure 1. SE Competency Framework Development Methodology

Figure 1 depicts the seven-step process applied throughout Chapters II through IV of this thesis in order to establish the proposed SSC Atlantic SE competency framework. The following section summarizes each of these steps.

1. Define the Role(s) of Systems Engineers at SSC Atlantic

In order to understand the role of a systems engineer, first the purpose of systems engineering will be examined, as well as the secondary disciplines or fields of study related to systems engineering that are frequently applied at SSC Atlantic. Next, the general role of an SSC Atlantic systems engineer will be defined, along with the different types of systems engineer roles, defined herein as "subroles."

2. Identify Existing Competency Model Frameworks

Identifying existing SE competency frameworks will require exploration into models currently used by organizations such as NASA, DAU, INCOSE and, most importantly, the Department of Navy and U.S. Marine Corps. There are also a number of fields of study that overlap with systems engineering. For example, project management, enterprise architecture and IT service management are all fields of practice that share

common process areas and correlated life cycle models with systems engineering. Because SSC Atlantic's mission within the DON focuses on delivering information technology (IT) solutions, the national cybersecurity workforce framework (NCWF) developed by NIST proves to be particularly relevant to the cause (National Initiative for Cybersecurity Education, 2013). There are also a number of leadership competencies and personal attributes, typically called soft skills or professional skills, such as verbal communication, conflict resolution and strategic thinking that enhance the proficiency and development of systems engineers. Exploring the KSAs associated with each of these fields can ultimately add value to the competency framework for a systems engineer.

3. Identify and Prioritize Competency Areas and KSAs that are Applicable to SSC Atlantic

Existing competency model frameworks for SE and related fields all come equipped with some mechanism with which to categorize KSAs. These categories, known as *competency areas*, each supply KSAs that are tailored at various competency level stages, which are defined in this study as entry, intermediate, advanced and expert. This step of the methodology first examines which competency areas from the frameworks identified in Steps 2 and 3 are most applicable to SSC Atlantic. Furthermore, specific KSAs from these competency areas are selected for inclusion into the SSC Atlantic competency development model. This step also involves prioritizing which competency areas and specific KSAs are most relevant to the role of an SSC Atlantic systems engineer.

4. Design and Build a Tailored Competency Framework That Addresses a Complete Set of Competency Areas and KSAs Desired for Systems Engineers

Once a complete set of prioritized competency areas and KSAs have been defined for the SSC Atlantic systems engineer, a new competency framework must be established which organizes competency areas and KSAs into high level competency vectors. Organizing this new competency framework into competency vectors will assist

engineering managers in communicating the general contents of the SSC Atlantic SE competency framework.

5. Identify Alternative Methods for Developing KSAs

Once a complete list of applicable competency areas and KSAs has been developed for SSC Atlantic systems engineers, the process for determining how individuals best develop these KSAs can begin. Basic methods for developing KSAs include OJT, educational training (degree and certification programs) and professional development.

6. Map KSAs to Optimal Workforce Development Methods

In order to determine the optimal development methods for systems engineering KSAs, decision criteria will be established. Using these decision criteria, each KSA in the newly established SSC Atlantic SE competency framework will be mapped to its optimal development method(s).

7. Develop and Assess Systems Engineers

This step will leverage the SE competency framework established in Steps 1 through 6 in order to develop SSC Atlantic systems engineers through the entry, intermediate, advanced and expert stages of the CDMs most applicable to their SE subroles. This step will also provide a high level overview for how to assess systems engineers (or any other role) against the associated CDM stages.

F. THESIS ORGANIZATION

This thesis is organized by chapters covering the following topics:

1. Chapter I: Introduction—describes the thesis background, purpose, the questions to be answered, projected benefits, methodology and content organization.
2. Chapter II: Problem Definition—This chapter summarizes the relevant research on the problem, defines the problem statement and provides context for the thesis. More specifically, this chapter defines the role of systems engineers at SSC Atlantic (Step 1), defines key terms associated with competency models and identifies competency models relevant to SE at SSC Atlantic (Step 2).

3. Chapter III: Applying SE Competency Areas to SSC Atlantic: This chapter discusses how KSA data is used at SSC Atlantic. This chapter also examines which competency areas and KSAs described in existing competency frameworks are most germane to how SSC Atlantic engages in systems engineering (Step 3).

4. Chapter IV: Designing a New Competency Framework for SSC Atlantic SE Roles and Subroles—This chapter establishes a new framework for SE competency development equipped with competency vectors relevant to the SSC Atlantic mission (Step 4). This chapter defines SSC Atlantic roles, subroles and their associated use cases.

5. Chapter V: A Model for Effective Systems Engineering Workforce Development at SSC Atlantic—This chapter discusses how the SSC Atlantic competency framework can be employed using alternative methods for employee development of KSAs (Step 5). This chapter describes each workforce development method and provides recommendations on where each is most appropriate for developing systems engineering KSAs (Steps 6 and 7). The chapter concludes with an overview for how to assess competency or proficiency levels against a CDM.

6. Chapter VI: Conclusions and Recommendations—This chapter summarizes the research, reiterates the key findings, and recommends areas for future research.

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II. PROBLEM DEFINITION

A. SYSTEMS ENGINEERING—THE CORE ELEMENTS

Since its formal beginning in the mid-twentieth century, systems engineering has been defined and redefined several times. In 1960, Flagle, Huggins and Roy stated that systems engineers “engage in the analysis of complex man and machine systems or one may also say man and machine operations, utilize multi-discipline teams, employ the scientific method, emphasize the ‘whole system’ rather than the component approach” (p. 23). This early definition wonderfully captures several of the key facets of systems engineering. The first key element of this definition is the concept that the human is actually part of the system and that systems are complex. The second point these pioneers make is that systems engineering requires multi-disciplinary teams. They also recognize the systematic or analytical approach that systems engineering must employ by referring to the “scientific method.” Lastly, they astutely identify the need for *systems thinking* in systems engineering, where one must take a holistic approach to solving system domain problems rather than over-emphasizing individual subsystems at the expense of the whole.

In his 1967 definition, Chestnut went on to highlight the difference between operating a system and engineering a system: “the overall problem of systems engineering is composed of two parts, one being the systems engineering associated with the way that the operating system itself works and the other with the systematic process of performing the engineering and associated work in producing the operating system” (p. 12). Modern day systems engineering life cycle models do not stop once the “engineering” part of the process is complete. Rather, they depict the operations, maintenance and disposal phases of the end-to-end process as well. During the 1990s, Checkland built upon these concepts by defining systems engineering as “the set of activities that together lead to the creation of a complex man-made entity and/or the procedures and information flows associated with its operation” (1993, p. 138). This particular definition highlights the interaction between components in a system.

Other modern day definitions of systems engineering include:

1. “The design of a complex interrelation of many elements (a system) to maximize an agreed-upon measure of system performance, taking into consideration all of the elements related in any way to the system, including utilization of worker power as well as the characteristics of each of the system’s components.” (Parker, 1994, p. 498)
2. “An interdisciplinary collaborative approach to derive, evolve, and verify a life-cycle balanced system solution which satisfies customer expectations and meets public acceptability.” (Institute of Electrical and Electronics Engineers [IEEE] 1220, 1998, p. 11)
3. “An interdisciplinary approach and means to enable the realization of successful systems.” (INCOSE, 2004, p. 12)

In addition to the core themes of interdisciplinary teams, complexity, human interactions and systems thinking, systems engineering is grounded in its basic processes of planning (arrangement of specific steps), designing (applying scientific and engineering methods) and management (skillfully leveraging resources). The last two definitions cited above from the Institute of Electrical and Electronics Engineers (IEEE) and INCOSE highlight the need for systems to meet customers’ expectations and be “successful,” alluding to the importance of meeting stakeholder needs.

B. PERSPECTIVES ON THE ROLE OF A SYSTEMS ENGINEER

The primary functions of a systems engineer (one who practices systems engineering) can be framed in various ways. However, there are a number of common trends that appear in the functions associated with a systems engineer. *The Systems Engineering Body of Knowledge* (SEBoK) highlights the following primary functions of a systems engineer: he or she:

- Supports an interdisciplinary approach
- Elicits and translates customer needs into specifications
- Supports the systems engineering life cycle processes
- Analyzes, specifies, designs and verifies the system to ensure that its functional, interface, performance, physical, and other quality characteristics—as well as cost—are balanced to meet the needs of the system
- Ensures the elements of the system fit together to accomplish the objectives of the whole

- Ultimately satisfies the needs of the customers and other stakeholders who will acquire and use the system (Pyster, Olwell, Hutchison, Enck, Anthony, Henry, & Squires, 2012, p. 5).

The GRCSE states that the role of the systems engineer includes:

- Understanding the intended purpose, operational context, and concept of use of the proposed system
- Appreciating the interests, purposes, values of multiple stakeholders and combining these into a coherent representation of the system requirements.
- Understanding the technology that may be applied in the system
- Appreciating the life cycle implications of systems and incorporating life cycle perspectives into systems design
- Evaluating, selecting, and developing system solutions to satisfy customer needs and project objectives (GRCSE, 2012, p. 1).

C. DEFINING THE ROLE OF THE SYSTEMS ENGINEER AT SSC ATLANTIC

Defining the KSAs required for a systems engineer in a complex organization such as SSC Atlantic comes with its challenges. The first challenge is defining the role of the systems engineer in a manner which can be accepted across a large, matrix organization. As of July 2013, SSC Atlantic consists of just over 4,000 U.S. government employees—over half of which work for the engineering department (actually known as the engineering "competency"). For the purposes of this paper, the SSC Atlantic engineering competency will be referred to as a "department" so as not to confuse it with the classical definition of "competency," which will be addressed later in the paper. The SSC Atlantic engineering department engineers, scientists, technicians and specialists are all involved in systems engineering in various capacities. Over 240 integrated product teams (IPTs) in SSC Atlantic work to deliver various IT-related end item products to Naval, Joint and Coalition warfighting customers. The range of engineering processes, technologies, missions and customers supported by the SSC Atlantic engineering department covers a wide spectrum. Determining the desired competency areas and KSAs for a lead systems engineer on any *one* of these IPTs may be a relatively straightforward task. However, determining a common set of KSAs for a lead systems

engineer for all 240 IPTs becomes significantly more challenging. This task requires observing the common duties or responsibilities associated with all of these roles.

In February 2013, SSC Atlantic engineering department leaders decided to establish the following core duties for an *IPT technical lead*, which is closely related to the role of a the lead systems engineer on an IPT:

- Identify scope of engineering/technical tasks on an IPT
- Determine what technical expertise is needed to support the IPT based on customer needs
- Determine the roles/KSAs needed on an IPT and when to submit demand signals out to the appropriate competencies
- Support/lead technical reviews for the IPT
- Responsible for the review of engineering/technical deliverables; Responsible for the technical quality of the work products produced by the IPT
- Work with portfolio systems engineers to integrate into enterprise architecture / system of systems / mission
- Serve as technical advisors for the IPT and adhere to the latest SSC Atlantic technical initiatives

An individual serving the role of an IPT technical lead may also serve as the IPT lead or program manager. The role of an SSC Atlantic IPT technical lead is compared to that of a systems engineer, as defined by the aforementioned sources in Table 1.

Systems Engineer Role Key Concepts	SEBoK	GRCSE	SSC Atlantic
Integrating different disciplines and technologies	X		X
Addressing operational / stakeholder needs	X	X	X
Systems Engineering life cycle processes	X	X	X
Requirements traceability through design, verification, validation	X	X	
System elements fitting together to meet the objectives of the whole	X		X
Satisfying customer needs	X	X	
Balancing cost, schedule and performance	X	X	

Table 1. SE Role Key Concepts Stressed by Different Organizations (After GRCSE, 2012, p. 1; Pyster et al., 2012, p. 9)

Comparing the SE role perspectives of SEBoK and GRCSE, both stress the importance of addressing operational needs, requirements traceability, balancing the tradeoffs between cost, schedule and performance, satisfying customer needs and SE life cycle processes. When comparing the SSC Atlantic IPT technical lead role to that of the systems engineer (as defined by SEBoK and GRCSE), there appears to be a gap in the areas of requirements traceability, customer needs satisfaction and the balancing of cost, schedule and performance (GRCSE, 2012, p. 1; Pyster et al., 2012, p. 9). However, there are other defined IPT roles within SSC Atlantic, which specifically address these three functional areas—the requirements engineer (who addresses requirements traceability), the tester (who validates user needs are met) and the project manager (who balances cost, schedule and performance). This frees up the IPT technical lead role to focus on areas of importance that are not stressed in classical systems engineering roles, such as those associated with scoping engineering tasks, managing engineering resources, planning technical reviews, and conducting technical deliverable reviews.

D. COMPETENCY AND COMPETENCY FRAMEWORKS

Simply understanding the basic duties that need to be performed in a role such as a systems engineer or a project manager is insufficient. One must also define the KSAs needed to perform those duties effectively and organize them in such a way for an individual to visualize a developmental roadmap for competency development. In order to understand the various competency model frameworks that can be leveraged to help define the developmental needs of systems engineers, one must first examine the basic concepts of competency and competency frameworks. The term *capability* refers to "the ability to deliver a product or service" (Holt & Perry, 2011, p. 5). In the context of this paper, the end goal is to improve SSC Atlantic's ability to provide the service of delivering superior IT solutions through systems engineering. In other words, the goal is to improve SSC Atlantic's systems engineering *capability*.

The term *competency* is defined as "an important skill that is needed to do a job" (Holt & Perry, 2011, p. 2) while a *competency framework* "describes a set of competencies (the 'things' that are measured to demonstrate competence) that are

applicable to a particular field" (Holt & Perry, 2011, p. 6). For the purposes of this paper, competencies are referred to as *competency areas*. These competency areas are made up of various knowledge, skills, and abilities (KSAs). Figure 2 illustrates how a competency framework can be subdivided into multiple competency areas, each of which contains any number of KSAs. KSAs can be developed via a number of workforce development methods. Professional development, OJT and other forms of workforce development methods are further defined and discussed in Chapter V. Competency models and frameworks also come equipped with "a scale for assessing the level of individual proficiency in each competency" (Pyster et al., 2012, p. 694).

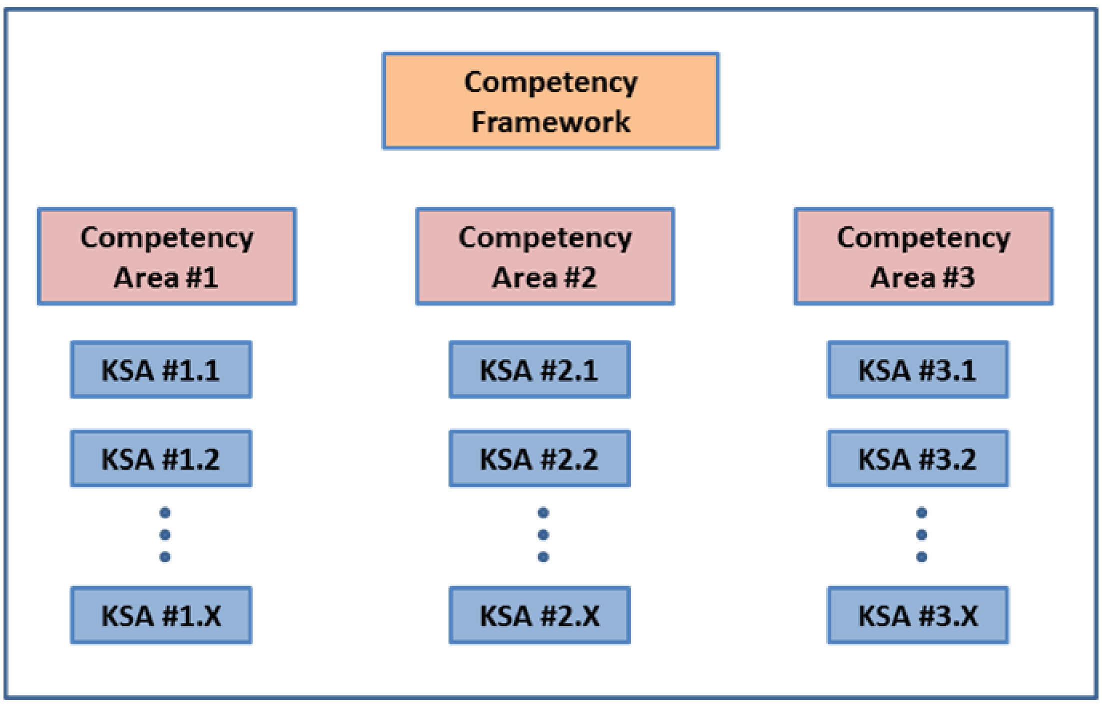

Figure 2. Basic Competency Framework with Associated Competency Areas and KSAs

When applied to systems engineering, KSAs can be characterized by groups of competency areas known as competency vectors or dimensions. Example competency vectors include systems engineering life cycle phase, product type, engineering discipline or mission area. The SEBoK asserts, "SE competency must be viewed through its relationship to the systems life cycle, the SE discipline, and the domain in which the

engineer practices SE" (Pyster et al., 2012, p. 694). Each of these perspectives may be its own competency vector. Figure 3 illustrates how competency vectors allow for the grouping of competency areas.

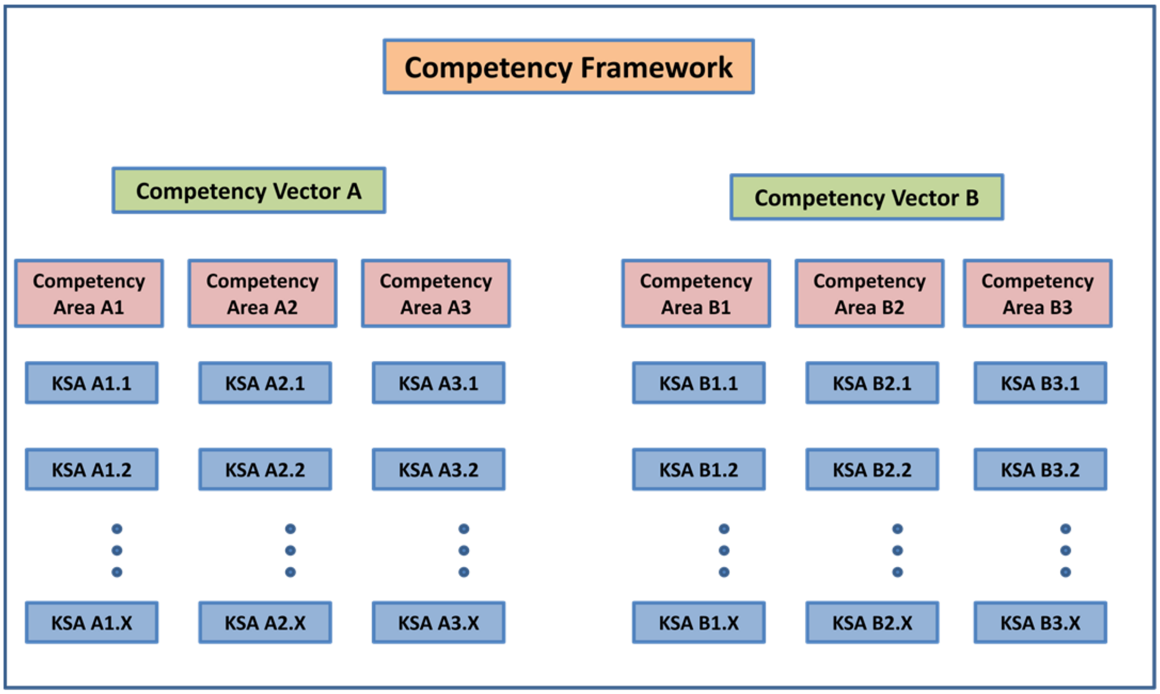

Figure 3. Competency Framework Employing Competency Vectors

E. SE COMPETENCY MODEL USE CASES

The SEBoK states that, "SE competency models can be used to explicitly state and actively manage the SE competencies within an organization" (Pyster et al., 2012, p. 694). More specifically, these competency models are useful in a number of organizational processes—namely hiring, IPT staffing, organizational capability development, and individual competency development. Appendix A depicts the process model for each of these. These organizational processes, or use cases are summarized as such:

- **Hiring**—KSAs defined in a competency model can be used throughout the recruiting and hiring process in order to fill needed positions. Potential candidates for employment that are assessed at higher CDM stages or with more of the requisite KSAs would be more likely to be selected/hired for systems engineering positions.

- **IPT staffing—**The IPT staffing process begins with an external customer's need for SE services. The IPT Lead then works with other members of engineering department management to determine what roles, subroles and KSAs are needed in order to provide those services. The appropriate engineering supervisors then use each employee's KSA data to determine who is the most capable of providing those needed services for a particular IPT assignment.
- **Organizational capability development & training identification—** Engineering department managers can look across the aggregate workforce to determine where employees are most competent (where they *have* the KSAs) and where they need further development (where they *don't* have the KSAs) in order to satisfy present and future demand for SE services. These KSA gaps in the workforce become priority competency areas where optimal workforce development methods should be identified and executed. For example, if a large portion of the engineering department workforce lacks the requisite KSAs to perform interface management, then a potential solution would be to develop or acquire structured interface management training that would address this capability gap.
- **Individual competency development—**Individuals understand which competency areas and KSAs they need to develop in order to advance through the entry, intermediate, advanced and expert stages of their SE role competency development model.

F. EXISTING SE COMPETENCY FRAMEWORKS

Within the DoD and industry, there are a number of existing SE competency frameworks that describe SE competency areas and associated KSAs. The SEBoK discusses and summarizes the SE competency models employed by INCOSE, MITRE, DAU, NASA, the Software Engineering Institute (SEI) and the capability maturity model integration (CMMI) as shown in Table 2. Each of these five competency models is relatively young, as the earliest (those of SEI and MITRE) were authored in 2007.

Competency Model Individual Level	Date	Author(s)	Purpose	Development Method	Competency Model
INCOSE UK WG	2010	INCOSE	Identify the competencies required to conduct good systems engineering	INCOSE Working Group	INCOSE (2010)
MITRE Competency Model	2007	MITRE	To define new curricula systems engineering and to assess personnel and organizational capabilities	Focus groups as described in Trudeau (2005)	Trudeau (2005), MITRE 2007
SPRDE-SE/PSE Competency Model	2010	DAU	Assess U.S. DoD Civilian acquisition workforce capabilities	DoD and DAU internal development	DAU (2010)
APPEL Competency Model	2009	NASA	To improve project management management and systems engineering at NASA	NASA internal development	APPEL (2009)
CMMI for Development	2007	SEI	Process improvement maturity model for the development of products and services	SEI Internal Development	SEI (2007)

Table 2. Summary of SE Competency Models (From Pyster et al., 2012, p. 696)

Rather than compare and contrast all five models, the three arguably most relevant to SSC Atlantic systems engineering will be discussed—DAU, NASA and INCOSE. The DAU SPRDE-SE/PSE competency model is the most highly correlated model as it is used DoD-wide and SSC Atlantic is a DoD/DON engineering and acquisition organization. As of April 2013, 878 SSC Atlantic employees were designated as being in a DAU SPRDE-SE/PSE billet. NASA—a Federal organization—has been a pioneer in the field of SE for decades. NASA offers a mature SE competency framework (known as the Academy of Program/Project Engineering Leadership (APPEL) competency model) centered on engineering and delivering complex systems. Therefore, the NASA APPEL model is largely relevant to the types of services that are provided at SSC Atlantic. The INCOSE model is perhaps the most pervasive competency model and is embraced by many members of the international SE community. INCOSE's SE competency model is closely correlated with those of DAU, NASA and other Federal/DoD organizations, but also offers industry's best-of-breed representation of a SE competency framework. INCOSE also administers the most well-known SE certification program in the world—Certified Systems Engineering Professional (CSEP).

While not discussed in this thesis, it should be noted that the Project Management Institute (PMI) and skills framework for the information age (SFIA) offer competency models in the areas of project/program management and information technology which

are both closely related to the discipline of systems engineering as well as highly relevant to the types of services commonly provided by SSC Atlantic.

G. COMPETENCY DEVELOPMENT MODEL STAGES

Competency models or frameworks typically come equipped with stages that define the levels of competence (or levels of KSAs) that an individual can develop in a given role. Most competency frameworks employ a three, four or five stage construct. For example, INCOSE uses the following four stage construct to define an individual's level of expertise at various competency development levels:

- **Stage 1**: **Awareness—**understands basic concepts; little to no experience
- **Stage 2**: **Supervised Practitioner—**some real experience of the competency; application of techniques and concepts as part of his/her work
- **Stage 3**: **Practitioner—**provides guidance and leads activities in this area; supervises and/or leads teams or groups of people
- **Stage 4**: **Expert—**leads the field in a particular area; defines best-practices, policies or processes within an organization or industry (INCOSE, 2010)

GRCSE uses the competency development levels or stages shown in Table 3.

Level I: Participate (Know)	Performs fundamental and routine SE activities while supporting a Level II-IV systems engineer as a member of a project team.
Level II: Apply (Perform)	Performs SE activities for a subsystem or simple project (e.g., no more than two simple internal/external interfaces, simpler contracting processes, smaller team/budget, and shorter duration).
Level III: Manage (Lead)	Performs as a systems engineer lead for a complex project (e.g., several distinct subsystems or other defined services, capabilities, or products and their associated interfaces).
Level IV: Guide (Strategize)	Oversees SE activities for a program with several systems and/or establishes SE policies at the top organizational level.

Table 3. GRCSE Competency Proficiency Levels (From GRCSE, 2012, p. 108)

Other competency frameworks employ very similar competency development (or proficiency) levels where, generally speaking, the first level is knowing or understanding; the second level is executing SE; the third level involves leading teams in SE; and the fourth level involves defining best practices, policies and generally governing how SE is accomplished within an entire organization. Chapter III examines SSC Atlantic's

implementation of a SE competency framework which utilizes a similar four-stage development concept.

H. COMPETENCY VECTORS

A competency vector (also known as a competency *dimension*), is a logical grouping of competency areas. Major competency vectors for a competency model vary from one framework to another. However, when compared side-by-side, the INCOSE, DAU SPRDE-SE/PSE and NASA SE competency frameworks display an interesting trend. All three frameworks address the SE *technical processes*, also known as the systems engineering “vee.” All three incorporate the SE *technical management processes* as well, encompassing such competency areas as risk management, requirements management and configuration management. All three incorporate various *supporting techniques* that span competency areas as system assurance, reliability/availability/maintainability (RAM), safety, and software engineering; however, these techniques are much more varied when compared between frameworks. All three frameworks also incorporate some form of competency vector associated with *leadership skills* or *personal attributes*. Two of the three (INCOSE and NASA) refer to some form of *domain* knowledge which provides the mission or context for why there is an operational need for the systems engineering being performed. The domain competency vector can encompass technology areas such as networks and sensors. The domain competency vector can also encompass engineering disciplines such as mechanical, electrical and structural engineering. Table 4 provides a side-by-side comparison of the three aforementioned SE competency frameworks and how they each address these five primary competency vectors.

	Competency Model		
Competency Vector	**INCOSE (2010)**	**DAU SPRDE-SE/PSE (2010)**	**NASA (2009)**
Technical Processes	Core Competencies (Sys Thinking, Holistic Lifecycle View)	Analytical Competencies (Technical Processes)	System Design & Product Realization
Technical Mgt Processes	Core Competencies (SE Mgt)	Technical Mgt Competencies	Technical Management
Supporting Techniques	Supporting Techniques	Analytical Competencies (System Assurance, Software Engineering, Safety, RAM)	Security, Safety & Mission Assurance
Domain	Domain Knowledge	N/A	Internal & External Environments
Leadership/Personal Attributes	Basic Skills and Behaviors	Professional Competencies	Professional & Leadership Development
Note: *NASA also has Human Capital Mgt & Knowledge Mgt as competency areas*			

Table 4. Comparison of INCOSE, DAU and NASA SE Competency Vectors

It should also be noted that the SEBoK states that there are typically four primary competency vectors (which they refer to as *dimensions*) to a SE competency model—disciplines, life cycle, domain and mission (Pyster et al., 2012, p. 709). The SEBoK cites aerospace and medical as two potential domain areas, for example (Pyster et al., 2012, p. 22). In the context of SSC Atlantic KSAs, the terms "domain" and "mission" can be used relatively interchangeably. Examples of domain or mission areas related to SSC Atlantic would include command and control, information operations and business operations. For the purposes of this paper, domain and mission are considered one in the same, as both provide context for the SE effort to be accomplished.

I. DEPARTMENT OF NAVY SYSTEMS ENGINEERING COMPETENCY DEVELOPMENT MODEL

As previously discussed, all three of the aforementioned SE competency frameworks provide tremendous value and are closely related to the SE practices

conducted at SSC Atlantic. So which framework should be chosen for tailoring at SSC Atlantic and the naval community at large?

A Pragmatic Guide to Competency states:

> When it comes to choosing between frameworks, then the scope of each and their intended audience becomes very important. This can lead to problems, however, as it is very rare that a single person will have their entire skillset chosen by a single framework…One way to address this is to look for a common reference that can be used as a starting point for mapping between the various competency frameworks. (Holt & Perry, 2011, p. 30)

Tasked by DASN RDT&E with bringing together and fusing the competency areas of the aforementioned SE competency frameworks in addition to those employed by Boeing and Naval Undersea Warfare Center (NUWC), the Naval Postgraduate School (NPS) has developed one common reference that can truly be used as the "north star" for Navy and U.S. Marine Corps SE organizations—the naval SE CDM. This thesis contributed to the development of the Naval SE CDM, which focuses on the competency vectors for SE technical processes, technical management processes and supporting techniques. The naval SE CDM deliberately leaves domain and leadership skill competency vectors outside of its scope for other, more appropriate competency reference models and frameworks to address and define. Figure 4 illustrates how five different competency models were fused into the naval SE CDM developed by the Naval Postgraduate School.

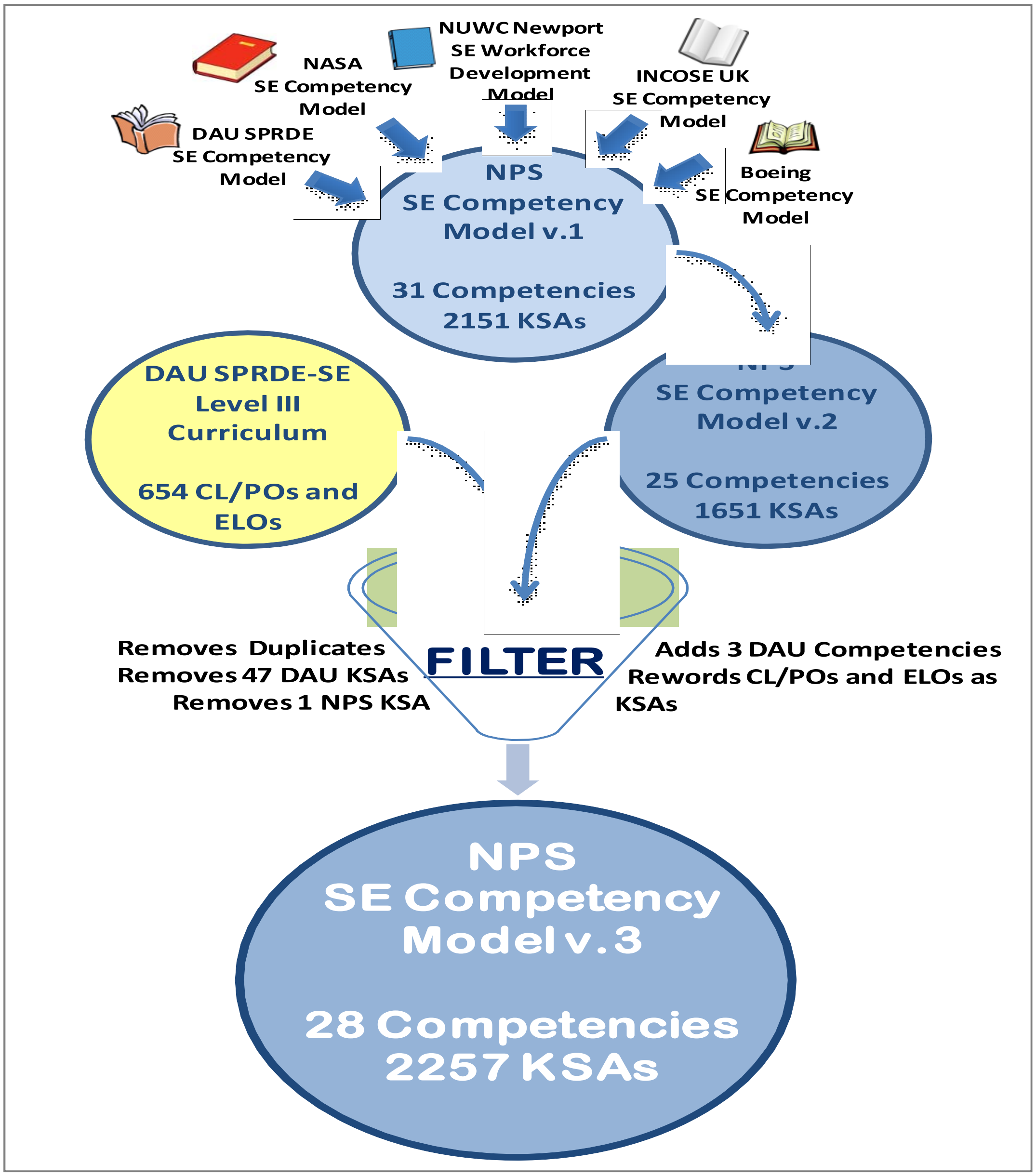

Figure 4. Evolution of the Naval SE CDM Developed by NPS (From Alexander, 2013, p. 29)

The result of the NPS competency model synthesis was 25 different competency areas (also known as competencies) with over 2,000 KSAs identified for the naval SE CDM. For the purposes of developing a SE competency framework for SSC Atlantic, the naval SE CDM provides a wide array of KSAs from which to choose, along with recommended CDM stages (levels) for each individual knowledge, skill or ability. It should be noted that three of the competency areas originally identified in Version 3 of

the naval SE CDM were removed from the model as they were not specific to systems engineering; hence, the mention of 28 competency areas (or competencies) in Figure 4. The resulting 25 naval SE CDM competency areas are as such:

- Technical basis for cost
- Modeling & simulation
- Safety assurance
- Stakeholder requirements definition
- Requirements analysis
- Architecture design
- Implementation
- Integration
- Verification
- Validation
- Transition
- System assurance
- Reliability, availability and maintainability (RAM)
- Decision analysis
- Technical planning
- Technical assessment
- Configuration management
- Requirements management
- Risk management
- Technical data
- Interface management
- Software engineering
- Acquisition
- Systems of systems
- Systems thinking

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III. APPLYING SE COMPETENCY AREAS TO SSC ATLANTIC

A. KNOWLEDGE, SKILLS AND ABILITIES FOR DIFFERENT USE CASES

Chapter II introduced various SSC Atlantic use cases that leverage KSA data. In order to determine which competency vectors, competency areas and associated KSAs SSC Atlantic should adopt for its diverse set of systems engineers, one must gain a deeper appreciation for how the KSA data will be used. Three of these use cases—recruiting/hiring, individual competency development and training identification highlight the need for KSA data at three completely different levels of granularity (or abstraction).

1. KSAs for Recruitment and Hiring of Systems Engineers

In order to recruit and hire an employee at SSC Atlantic, a hiring package must be developed which includes position description information. This position description includes information such the individual's pay grade, job series and clearance requirements. It also includes information regarding the individual's duties and KSAs. For a typical hiring package, there are approximately five KSAs cited in the position description. Therefore, when recruiting and hiring a new systems engineer into the SSC Atlantic organization, only a limited set of KSAs will actually be specified. This requires the systems engineering KSAs to be used for the purpose of hiring and recruitment to be very broad. For example, if there are five competency vectors relevant to a systems engineer's assigned duties, then the position description would only refer to about one KSA per competency vector. A shortened KSA for such a case might read something like, "knowledge of the systems engineering technical management processes" or "basic understanding of command and control as it applies to IT systems."

2. KSAs for Individual Competency Development

Since 2008, SSC Atlantic competency development models (CDMs) for engineering divisions have typically consisted of approximately 10 to 15 KSAs per competency development stage. For example, a systems engineer currently certified at

the intermediate stage might be required to demonstrate proficiency in 12 different KSAs in order to progress to the level of advanced. Since there are four stages in an SSC Atlantic CDM, this equates to roughly 50 KSAs per CDM for any given role that individual might fulfill. In this case, we have approximately ten times as many KSAs defined for a systems engineer than we do in the use case associated with hiring and recruitment. For this level of detail, it would be insufficient to simply state that a systems engineer must have "knowledge of the systems engineering technical management processes." Instead, a basic KSA for a systems engineer's CDM might read something like, "ability to perform requirements management," where requirements management is one of many technical management processes.

3. KSAs for the Identification of Training Needs

When individuals seek to develop specific KSAs for which they demonstrate little to no proficiency, they may seek to find available training opportunities. Oftentimes, the level of KSA granularity described in an SSC Atlantic CDM of approximately 50 KSAs is insufficient. For example, a systems engineer may need to develop a basic ability or skill in using requirements management tools. In the CDM for a systems engineer, one might find the KSA, "ability to perform Requirements Management for complex IT systems." However, more detailed KSAs might not be identified for requirements management tools. For this reason, there is an additional need for an even larger quantity of KSAs to be specified for systems engineers that may add up to the hundreds or even thousands of KSAs. This allows a systems engineer to search for KSAs and associated training opportunities that can fulfill unique developmental needs. For SSC Atlantic, Total Workforce Management Services (TWMS) is the tool used to search for KSAs, find associated training opportunities and add these training events to individual development plans. Table 5 summarizes the three primary use cases for KSA usage and how they differ in terms of the typical quantity of KSAs they use. Figure 5 illustrates how a single KSA used for recruiting and hiring translates into usage in the other two use cases.

Use Case	Source	Typical # of KSAs
Recruiting & Hiring	Position description for the job of a systems engineer	5
Individual Competency Development	CDM for a systems engineer	50
Training Needs Identification	Total Workforce Management Services (TWMS) KSA & Training Database	500

Table 5. SSC Atlantic KSA Use Cases and Typical KSA Quantities

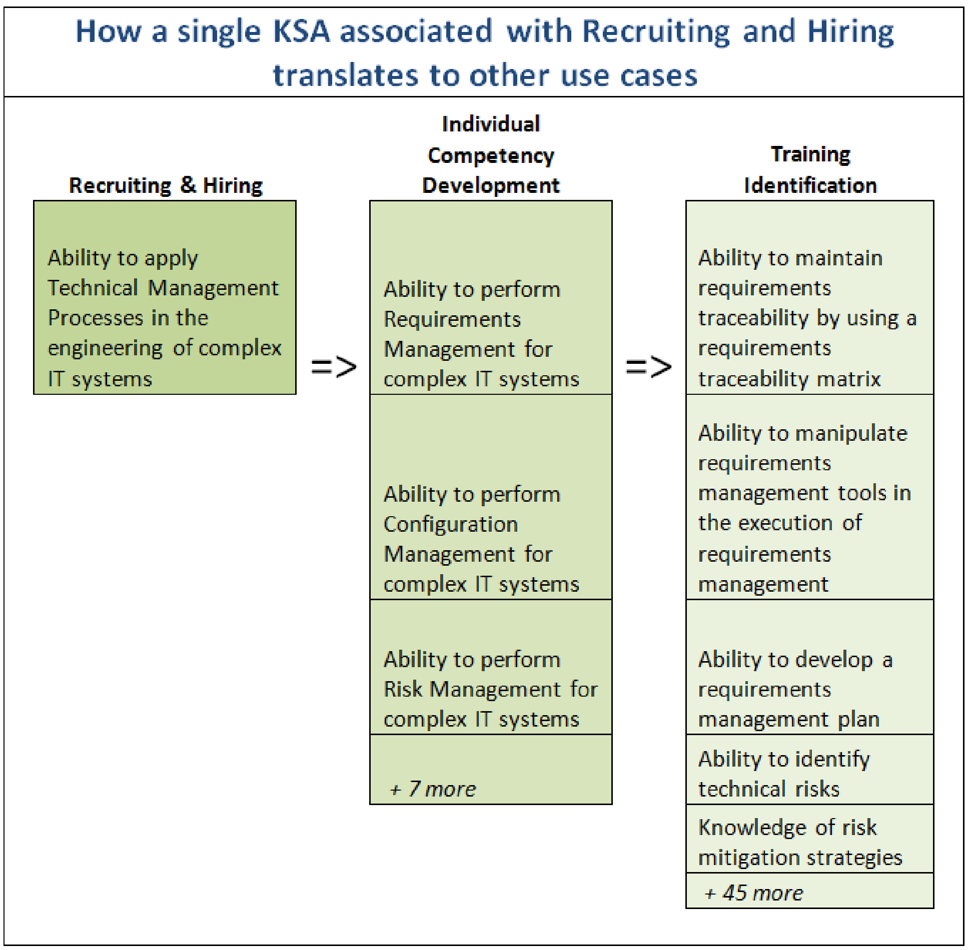

Figure 5. How a KSA Associated with One Use Case Translates to Other Use Cases

B. APPLYING BLOOM'S TAXONOMY TO CLARIFY DESIRED KNOWLEDGE, SKILLS AND ABILITIES

KSAs can be stated at any level of granularity to fit the need of their use and are stratified across various competency development or proficiency stages, such as entry, intermediate, advanced and expert. KSAs can also be classified by Bloom's taxonomy into three different domains and categories. Dr. Benjamin Bloom created Bloom's taxonomy in 1956 in order to encourage the developing of KSAs in ways other than just memorization of facts. This led to the definition of three learning domains—cognitive, affective and psychomotor (Bloom, 1956). The cognitive domain involves knowledge and the development of intellectual skills (Bloom, 1956). GRCSE focuses more heavily on the cognitive domain than the other two domains. The psychomotor domain is arguably the least relevant to SE KSAs, as it focuses primarily on physical skills. However, the affective domain, which focuses on dealing with emotions, can also play a key role in the development of systems engineers in the systems thinking competency area. The GRCSE highlights the importance of systems engineers developing KSAs in the affective domain:

> A key role of the systems engineer is to lead the development of systems. This role includes working with engineered systems, deliberately taking a systems perspective, and negotiating solutions with multiple, diverse stakeholders. These requirements of a systems engineer make their proficiency in the attributes of the affective domain critical to their success. (GRCSE, 2012, p. 86)

The cognitive and affective domains of Bloom's taxonomy are each subdivided by categories as shown in Figure 6.

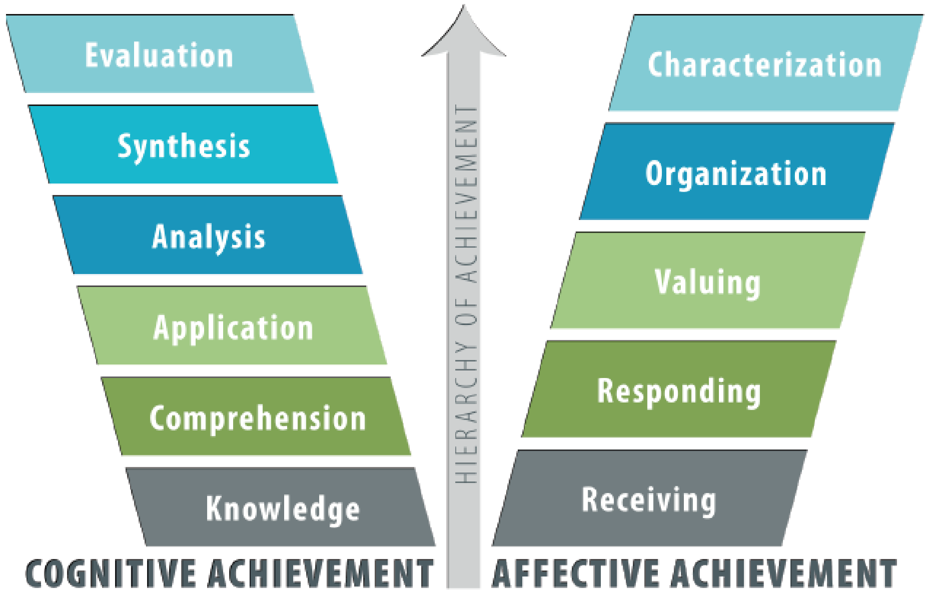

Figure 6. Bloom's Taxonomy in the Cognitive and Affective Domains and the Hierarchy of Achievement (From GRCSE, 2012, p. 86)

A key feature of the naval SE CDM is that it tags each of its KSAs with the Bloom's domain and category levels that are most applicable. The GRCSE asserts that, within Bloom's categories or levels, as shown in Figure 6:

> …progression from one level to another is not only the result of more study, but also results from the direction of the study effort to develop a different kind of capability. For example, progression from 'Knowledge' to 'Comprehension' is not attained by the same type of studying that achieved the original knowledge… Similarly, 'Analysis' and 'Synthesis' are different kinds of skills that involve different approaches to thinking about the subject matter… synthesis is not simply more analysis, but rather a different kind of activity based on a different kind of learning. (GRCSE, 2012, p. 87)

Certain key verbs can help in classifying a knowledge, skill or ability into a Bloom's domain and category/level. For example, the ability to apply (the "application" category of the cognitive domain) might use verbs such as demonstrate, employ, illustrate or produce. Tables 6 and 7 from highlight examples and the key verbs that are commonly associated with each of Bloom's cognitive and affective domain levels. Categorizing KSAs in this manner will prove useful in Chapter V, which looks at the optimal ways of developing KSAs.

Category	Example and Key Verbs
Remembering (Knowledge): Recall previous learned information.	**Examples**: Recite a policy. Quote prices from memory to a customer. Knows the safety rules. **Key Words**: defines, describes, identifies, knows, labels, lists, matches, names, outlines, recalls, recognizes, reproduces, selects, states.
Understanding (Comprehension): Comprehending the meaning, translation, interpolation, and interpretation of instructions and problems. State a problem in one's own words.	**Examples**: Rewrites the principles of test writing. Explain in one's own words the steps for performing a complex task. Translates an equation into a computer spreadsheet. **Key Words**: comprehends, converts, defends, distinguishes, estimates, explains, extends, generalizes, gives an example, infers, interprets, paraphrases, predicts, rewrites, summarizes, translates.
Applying (Application): Use a concept in a new situation or unprompted use of an abstraction. Applies what was learned in the classroom into novel situations in the work place.	**Examples**: Use a manual to calculate an employee's vacation time. Apply laws of statistics to evaluate the reliability of a written test. **Key Words**: applies, changes, computes, constructs, demonstrates, discovers, manipulates, modifies, operates, predicts, prepares, produces, relates, shows, solves, uses.
Analyzing (Analysis): Separates material or concepts into component parts so that its organizational structure may be understood. Distinguishes between facts and inferences.	**Examples**: Troubleshoot a piece of equipment by using logical deduction. Recognize logical fallacies in reasoning. Gathers information from a department and selects the required tasks for training. **Key Words**: analyzes, breaks down, compares, contrasts, diagrams, deconstructs, differentiates, discriminates, distinguishes, identifies, illustrates, infers, outlines, relates, selects, separates.
Evaluating (Evaluation): Make judgments about the value of ideas or materials.	**Examples**: Select the most effective solution. Hire the most qualified candidate. Explain and justify a new budget. **Key Words**: appraises, compares, concludes, contrasts, criticizes, critiques, defends, describes, discriminates, evaluates, explains, interprets, justifies, relates, summarizes, supports.
Creating (Synthesis): Builds a structure or pattern from diverse elements. Put parts together to form a whole, with emphasis on creating a new meaning or structure.	**Examples**: Write a company operations or process manual. Design a machine to perform a specific task. Integrates training from several sources to solve a problem. Revises and process to improve the outcome. **Key Words**: categorizes, combines, compiles, composes, creates, devises, designs, explains, generates, modifies, organizes, plans, rearranges, reconstructs, relates, reorganizes, revises, rewrites, summarizes, tells, writes.

Table 6. Categories of Bloom’s Cognitive Domain (After Bloom’s Taxonomy of Learning Domains, 2013)

Category	Example and Key Verbs
Receiving Phenomena: Awareness, willingness to hear, selected attention.	**Examples**: Listen to others with respect. Listen for and remember the name of newly introduced people. **Key Words**: asks, chooses, describes, follows, gives, holds, identifies, locates, names, points to, selects, sits, erects, replies, uses.
Responding to Phenomena: Active participation on the part of the learners. Attends and reacts to a particular phenomenon. Learning outcomes may emphasize compliance in responding, willingness to respond, or satisfaction in responding (motivation).	**Examples**: Participates in class discussions. Gives a presentation. Questions new ideals, concepts, models, etc. in order to fully understand them. Know the safety rules and practices them. **Key Words**: answers, assists, aids, complies, conforms, discusses, greets, helps, labels, performs, practices, presents, reads, recites, reports, selects, tells, writes.
Valuing: The worth or value a person attaches to a particular object, phenomenon, or behavior. This ranges from simple acceptance to the more complex state of commitment. Valuing is based on the internalization of a set of specified values, while clues to these values are expressed in the learner's overt behavior and are often identifiable.	**Examples**: Demonstrates belief in the democratic process. Is sensitive towards individual and cultural differences (value diversity). Shows the ability to solve problems. Proposes a plan to social improvement and follows through with commitment. Informs management on matters that one feels strongly about. **Key Words**: completes, demonstrates, differentiates, explains, follows, forms, initiates, invites, joins, justifies, proposes, reads, reports, selects, shares, studies, works.
Organization: Organizes values into priorities by contrasting different values, resolving conflicts between them, and creating an unique value system. The emphasis is on comparing, relating, and synthesizing values.	**Examples**: Recognizes the need for balance between freedom and responsible behavior. Accepts responsibility for one's behavior. Explains the role of systematic planning in solving problems. Accepts professional ethical standards. Creates a life plan in harmony with abilities, interests, and beliefs. Prioritizes time effectively to meet the needs of the organization, family, and self. **Key Words**: adheres, alters, arranges, combines, compares, completes, defends, explains, formulates, generalizes, identifies, integrates, modifies, orders, organizes, prepares, relates, synthesizes.
Internalizing values (Characterization): Has a value system that controls their behavior. The behavior is pervasive, consistent, predictable, and most importantly, characteristic of the learner. Instructional objectives are concerned with the student's general patterns of adjustment (personal, social, emotional).	**Examples**: Shows self-reliance when working independently. Cooperates in group activities (displays teamwork). Uses an objective approach in problem solving. Displays a professional commitment to ethical practice on a daily basis. Revises judgments and changes behavior in light of new evidence. Values people for what they are, not how they look. **Key Words**: acts, discriminates, displays, influences, listens, modifies, performs, practices, proposes, qualifies, questions, revises, serves, solves, verifies.

Table 7. Categories of Bloom’s Affective Domain (After Bloom’s Taxonomy of Learning Domains, 2013)

C. SSC ATLANTIC ENGINEERING PROCESS FRAMEWORK

There are a number of different life cycle models that serve as a guide for conducting engineering and acquisition processes. The Project Management Body of Knowledge (PMBoK) provides a framework for projects of varying sizes and degrees, spanning project initiation, planning, execution, monitoring/control and closeout. For the Department of Defense, the defense acquisition management framework provides an event-based process in which "acquisition programs proceed through a series of milestone reviews and other decision points that may authorize entry into a significant new program phase" (Defense Acquisition University, 2011).

The systems engineering "Vee" is commonly used to describe the systems engineering processes associated with requirements development, design, implementation, integration, verification, validation operations and sustainment. The *SPAWAR Systems Engineering Guidebook* (SSEG), which is used by SPAWAR Headquarters, SSC Atlantic and SSC Pacific, adopts a similar model as shown in Figure 7, which depicts the original SSEG process framework. Here the technical management processes are shown across the top to represent that they are conducted throughout the project and systems engineering life cycle. The classical SE "Vee" is shown in the center of the diagram through the solution design and production realization processes. As of July 2013, the SSEG remains in beta form and continues to be revised by the SPAWAR engineering department. Figure 8 depicts the updated SSEG process framework, which has abandoned the SE "Vee" visual.

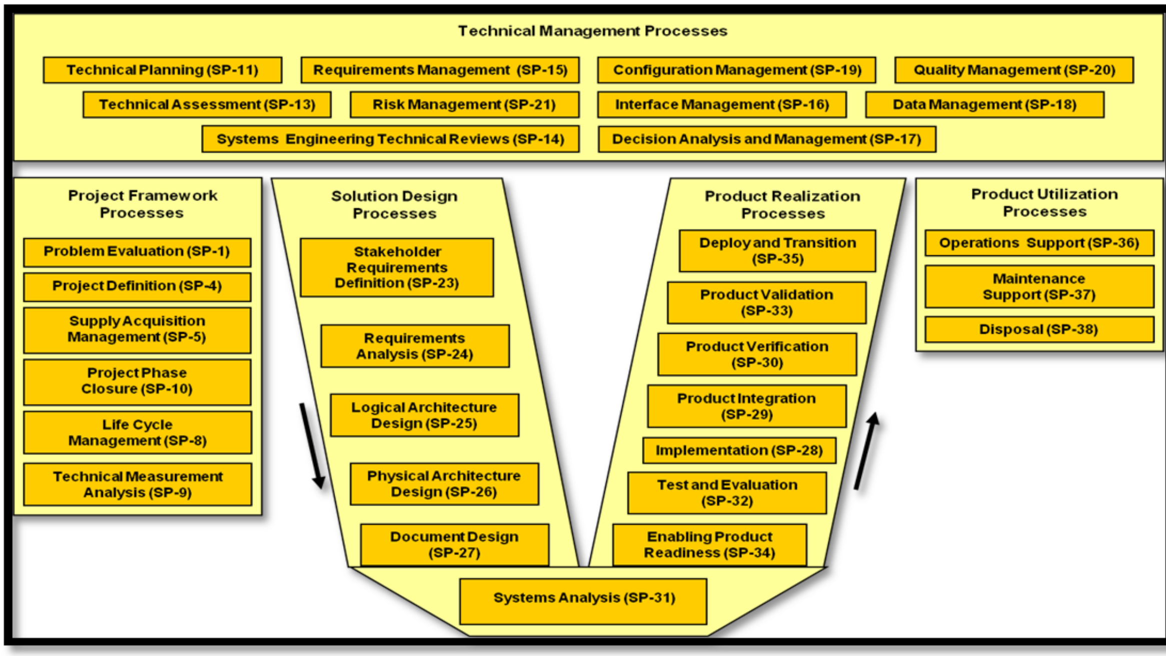

Figure 7. Original SSEG Process Framework

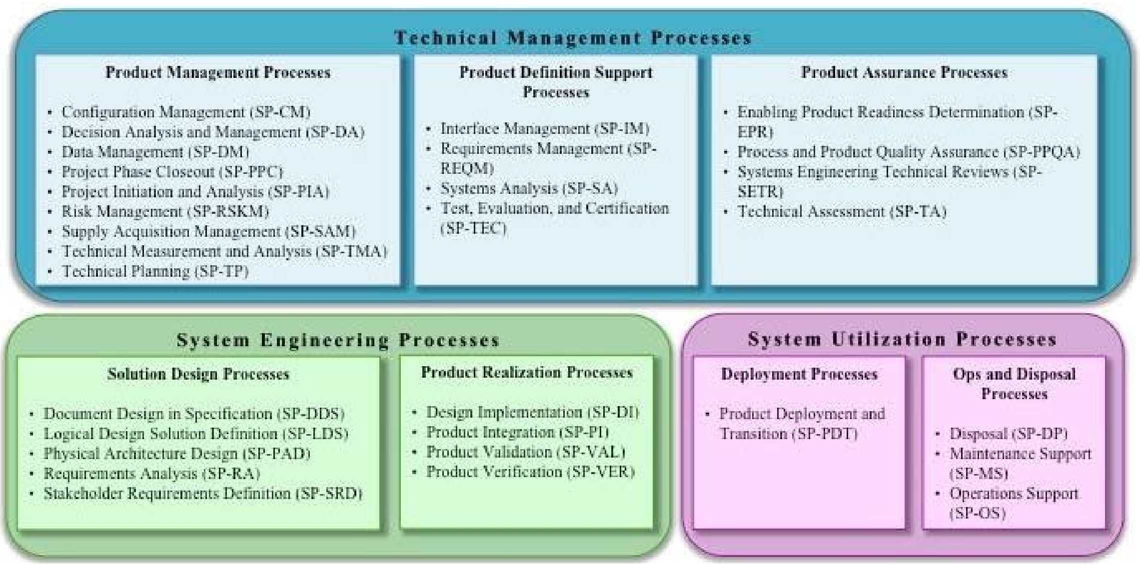

Figure 8. SSEG Process Framework as of July 2013

In May 2013, SSC Atlantic established Version 1.0 of the SSC Atlantic Systems Engineering Framework that organizes its SE process areas at the highest level by the SSC Project Lifecycle, also known as the PLC. Figure 9 shows how the PLC combines

basic elements of the PMBoK project management life cycle such as project initiation, planning and closeout with systems engineering process areas such as requirements development, design, integration, testing, operations and sustainment. Hence, the PLC represents the complementary nature within SPAWAR of the role of the program or project manager with that of the systems engineer. The *SSC Atlantic Systems Engineering Framework Version 1.0*, depicted in Figure 10, shows how the PLC is supported by engineering guidance set forth in the *Naval Systems Engineering Guide*, *SSEG*, *Defense Acquisition Guidebook* and other organizational standard processes as well as by the technical management and technical/engineering processes commonly found in SE life cycle models.

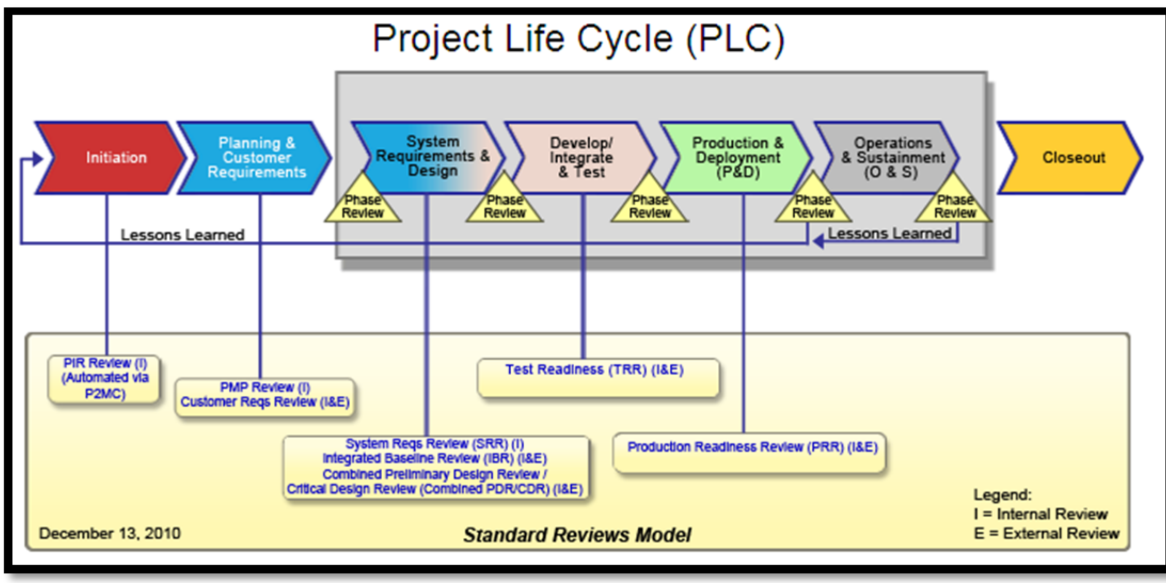

Figure 9. Project Life Cycle

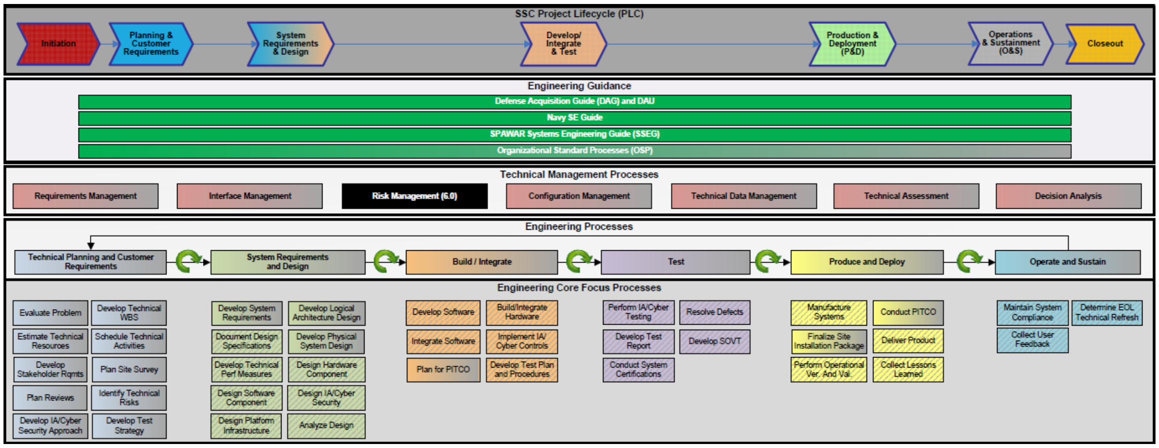

Figure 10. SSC Atlantic SE Process Framework v1.0

While at the first level, the *SSC Atlantic SE Framework* leverages the PLC as a general lifecycle guide, at the second level, the Engineering Processes align with the competency areas as defined in the *Naval SE CDM*. For example, requirements management, interface management and risk management are depicted as technical management processes, while stakeholder requirements definition and requirements analysis show up as engineering processes, which are very closely aligned to DAU technical processes. The *SSC Atlantic SE Framework* serves as a guide for systems engineers to discover related standard operating procedures, tools, templates, checklists and other aids that can assist them with executing SE processes and developing related KSAs. The latest version of the *SSC Atlantic SE Process Framework* is scheduled to be published to the *SSC Atlantic Command Operating Guide* by the end of calendar year 2013.

D. COMPETENCY VECTORS RELEVANT TO SE AT SSC ATLANTIC

While the systems engineering life cycle process framework plays a major role in framing and defining the KSAs of systems engineers at SSC Atlantic, it is not the only dimension or competency vector. It is also important for systems engineers to understand *why* they are engineering and supporting the solutions they are delivering. For that reason, a critical competency vector for SSC Atlantic systems engineers must be associated with the domain or *mission* that the engineered solutions ultimately support. For example, a naval command and control (C2) or information operations (IO) mission

may require IT systems that transmit certain types of information, improve critical mission times or provide more robust warfighting capabilities. Such mission or capability areas can be framed in a variety of different ways. For example, the Joint Capability Areas (JCAs) can be used to provide a high level framework for the capability areas associated with Joint services. In order for a systems engineer to effectively fulfill any such capability gaps, he or she must truly understand the real problem at hand in a holistic manner.

SSC Atlantic's vision statement is to "Make IT Count for the Warfighter and the Nation." IT is defined as "the application of computers and telecommunications equipment to store, retrieve, transmit and manipulate data" (Daintith, 2009). By taking a closer look at the definition of IT, a major competency vector can be established for the development of IT-savvy systems engineers. The *application* portion of this definition refers to the SE process areas as the root term "apply" means "to put to use," which makes sense as SE is a "means to enable the realization of successful systems" (INCOSE, 2004, p. 12). The other major component of IT is the technology itself—computers and telecommunications equipment. Within SSC Atlantic, the major technology areas most commonly associated with IT are networks, radio frequency (RF) communications, computer applications and sensors. In fact, several hundred systems engineers at SSC Atlantic are aligned to networks, communications or computer applications as their primary competency area. This naturally leads to a third competency vector, which will be referred to as "technology." Figure 11 depicts the three primary competency vectors for SSC Atlantic systems engineers—mission, technology and activities (SE life cycle processes).

Figure 11. Three Primary Competency Vectors for SSC Atlantic Systems Engineers

The fourth and final competency vector critical to the development of systems engineers at SSC Atlantic is one that is core to practically any employee in any workplace environment—*leadership skills*. Figure 12 depicts the four-vector competency framework of mission, technology, activities and leadership skills. Leadership skills typically encompass skills or attributes such as those related to oral and written communications, conflict management, team building, strategic thinking, customer service and integrity. Appendix B provides a complete breakdown of the leadership skills (otherwise known as personal attributes), definitions/indicators and recommended competency development stage/level. These leadership skills are summarized below:

- Accountability
- Communication (oral and written)
- Conflict management
- Continual learning
- Creativity / innovation
- Customer service
- Decisiveness / problem solving

- Entrepreneurship
- External awareness / political savvy
- Financial management
- Flexibility / resilience
- Human capital management
- Information management
- Integrity / honesty
- Interpersonal skills
- Leadership / influence / negotiation
- Partnering / collaborative performance
- Self-management
- Service motivation
- Strategic thinking / vision
- Team building
- Technical expertise
- Technology credibility
- Technology management

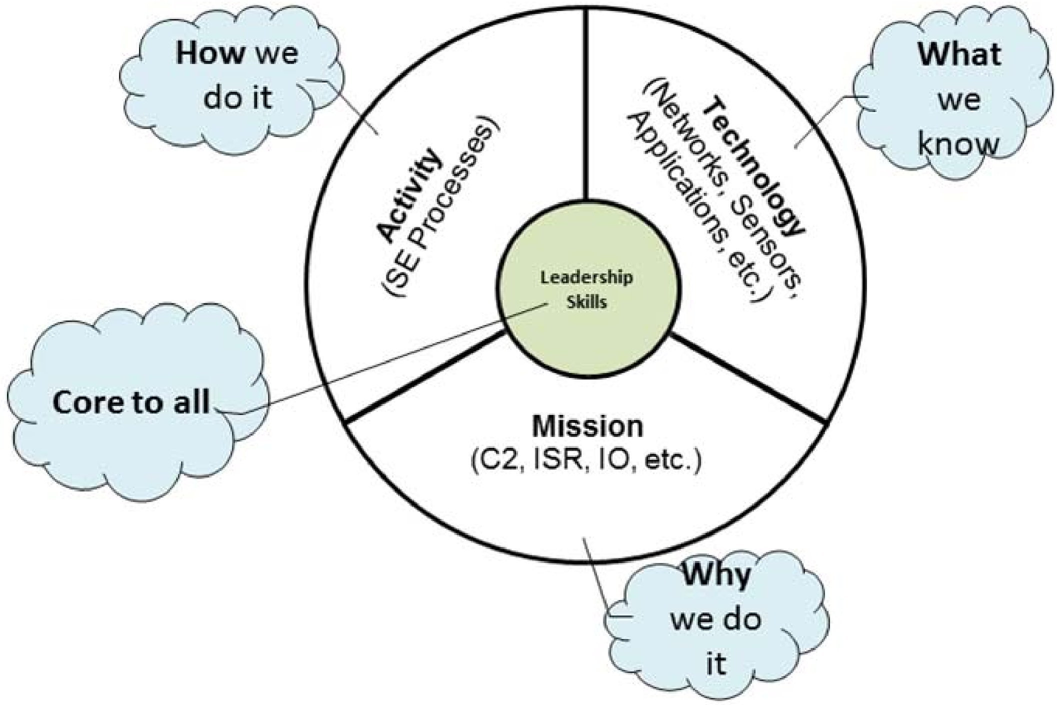

Figure 12. SSC Atlantic Four-vector SE Competency Framework

E. PRIORITIZATION OF SE COMPETENCY AREAS

In his brief entitled, "A Framework to Institutionalize Systems Engineering Skill-Set" Ebad Jahangir examines the SE competency frameworks from NASA and INCOSE and makes the recommendation that there are five primary "critical skills" (most closely related to competency vectors)—systems thinking, systems architecture, technical management, product realization and leadership skills (2012). Table 8 depicts Jahangir's five critical skills and associated enabling skills (much like competency areas). *Systems thinking*, as defined by INCOSE, maps effectively to the systems thinking competency area defined by the naval SE CDM, as well as the mission/capability focus as addressed by the mission competency vector. INCOSE's *system architecture*, *technical management* and *product realization* are directly traceable to the SE lifecycle (activity) competency areas. The *leadership skills* map directly to the leadership skills or personal attributes competency vector.

Critical Skill	Enabling Skills
Systems Thinking	Business and technology environment Super-system capability issues Systems concepts
System Architecture	Stakeholder Expectation Definition Technical Requirements Definition Logical Decomposition Design Solution Definition
Technical Management	Technical Planning Requirements Management Interface Management Technical Risk Management Configuration Management Technical Data Management Technical Assessment Technical Decision Analysis
Product Realization	Product Implementation Product Integration Product Verification Product Validation Product Transition
Leadership Skills	Coaching Communication: Verbal, non-verbal and listening Communication: Technical report writing Knowing when to ask Lateral thinking Negotiation and influencing Team working

Table 8. Jahangir's Five Critical Skills (Competency Vectors) for Systems Engineers (From Jahangir, 2012)

While Jahangir's model (as well as those of INCOSE, DAU and NASA) may not reflect the IT focus of SSC Atlantic, the national cybersecurity workforce framework (NCWF) developed by NIST does. According to NIST, "The *National Cybersecurity Workforce Framework* establishes the common taxonomy and lexicon that is to be used to describe all cybersecurity work and workers irrespective of where or for whom the work is performed" (NIST, 2011, p. 7). The NCWF defines typical cybersecurity workforce tasks and KSAs needed in the areas of network services, telecommunications, and computer applications in sufficient detail to support the hiring/recruiting and individual competency development SSC Atlantic use cases.

Chapter V, Section E discusses five common SE use cases that may be encountered by an SSC Atlantic IPT. Each of these SE use cases emphasizes the importance of different competency areas and competency vectors. Table 9 depicts which competency areas and vectors are emphasized in each use case by placing an "X" in the appropriate cell. The *Total SE Use Case Score* is determined by adding up the number of use cases which stress the respective competency area or vector. Table 9 also depicts the result of an analysis conducted by Gelosh in *What Defines a Systems Engineer? Comparing and Contrasting Global Perspectives on Systems-Engineering Competency*. Gelosh's analysis compared the relative importance or emphasis of a particular SE competency area to the DoD versus industry (understood as settings outside of the DoD). The far right column of Table 9 takes the average score of the Total SE Use Case Score, Gelosh's DoD Score and Gelosh's Industry Score to provide a final score for each competency area and vector. In summary, this average or final score shown on the far right of Table 9 considers various SSC Atlantic SE use cases, the DoD's emphasis and the emphasis of Industry at large to prioritize the relative importance for each of the competency areas and vectors to be used by SSC Atlantic. Competency areas and vectors with final scores above 3.5 are considered to be most important. Competency areas and vectors with final scores of 3.0 to 3.5 are considered moderately important, while those with scores under 3.0 are considered mildly important. It should be noted that sensitivity analysis with weighting of the SSC Atlantic use cases and Gelosh's scores with respect to each other shift the rankings to a certain degree, but not significantly.

	SE Use Cases *(X = competency area or vector emphasized)*						**Gelosh Comparison**		**Avg of SE Use Case, DoD & Industry Scores**
Competency Area (or Vector)	**Component Engineering**	**Simple SE**	**Complex SE**	**Platform SE**	**SoSE**	**Total SE Use Case Score**	**DoD Score**	**Industry Score**	
Stakeholder Requirements Definition	X	X	X	X	X	**5**	4	4	4.33
Requirements Analysis	X	X	X	X	X	**5**	3	4	4.00
Architecture Design	X	X	X	X	X	**5**	3	4	4.00
Software Engineering		X	X	X	X	**4**	4	4	4.00
Acquisition	X	X	X	X	X	**5**	3	4	4.00
Technology Competency Vector	X	X	X	X		**4**	N/A	N/A	4.00
Technical Basis for Cost	X	X	X	X	X	**5**	3	3	3.67
Verification	X	X		X		**3**	4	4	3.67
System Assurance		X	X	X	X	**4**	4	3	3.67
Decision Analysis	X	X	X			**3**	4	3	3.33
Technical Planning		X	X	X	X	**4**	4	2	3.33
Configuration Management		X	X	X	X	**4**	3	3	3.33
Requirements Management			X	X	X	**3**	4	3	3.33
Risk Management			X	X	X	**3**	4	3	3.33
Technical Data Management		X	X	X	X	**4**	3	3	3.33
Interface Management			X	X	X	**3**	4	3	3.33
Implementation	X	X	X	X		**4**	2	3	3.00
Integration			X	X	X	**3**	3	3	3.00
Validation			X	X	X	**3**	4	2	3.00
Transition		X	X	X		**3**	2	4	3.00
Systems Thinking			X	X	X	**3**	N/A	N/A	3.00
Mission Competency Vector			X	X	X	**3**	N/A	N/A	3.00
Modeling & Simulation			X	X	X	**3**	2	3	2.67
Reliability, Availability & Maintainability	X	X				**2**	2	4	2.67
Technical Assessment			X	X	X	**3**	4	1	2.67
Safety Assurance				X		**1**	4	2	2.33
Systems of Systems			X	X	X	**3**	1	1	1.67

Table 9. Ranking the Emphasis of Competency Areas and Vectors against Various SE Use Cases. Gelosh Comparison Addresses DoD versus Industry Perspective (After Gelosh, 2009)

Of the most important competency areas and vectors, the stakeholder requirements definition, requirements analysis and architecture design competency areas all represent processes near the beginning of the SE life cycle. The importance of these process areas underscores the need to get the requirements and architecture "right," lest the total cost of ownership for the system increase significantly over the course of the life of the system. Other noteworthy process areas that scored high include software engineering and system assurance—two competency areas that have continued to increase in importance over the last several years due to systems' reliance on software and the need for cybersecurity.

Even though some processes were rated as mildly important, that is not to say that they are not critical. One challenge with the systems of systems competency area is that this use case only represents a small percentage of total projects; therefore, it is not currently emphasized a great deal. It is also difficult to train systems engineers in systems of systems engineering (SoSE) as the methodologies associated with SoSE are still relatively immature. Systems thinking is another competency area that is arguably very critical to SE, yet it is not very prescriptive, and thus does not translate effectively to a well-defined process that can be monitored and controlled. Safety assurance also fell into the lower-scoring category primarily due to the fact that it is simply a discipline that is not as critical in the IT domain as in those of a more physical realm.

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IV. DESIGNING A NEW COMPETENCY FRAMEWORK FOR SSC ATLANTIC SE ROLES AND SUBROLES

A. SSC ATLANTIC SE COMPETENCY FRAMEWORK

Chapter II provided an analysis of the anatomy of a competency framework in terms of competency vectors, competency areas and associated KSAs. Chapter II also highlighted the critical competency vectors and competency areas associated with performing systems engineering at SSC Atlantic. By defining the critical competency vectors of SSC Atlantic systems engineering to be *missions, activities* and *technologies*, the *SSC Atlantic systems engineering competency framework* depicted in Figure 13 is established. The competency vector associated with leadership skills is not explicitly depicted in the framework since it applies more broadly to the entire SSC Atlantic (or practically any) workforce—not just to systems engineers. Within each of the competency vectors, there are several competency areas under which KSAs are defined. These KSAs originate from each of the sources defined in the previous chapters (namely the naval SE CDM, INCOSE, DAU, NASA and NIST) as well as from existing SSC Atlantic engineering CDMs. Each individual KSA is assigned an associated competency development stage—entry, intermediate, advanced or expert.

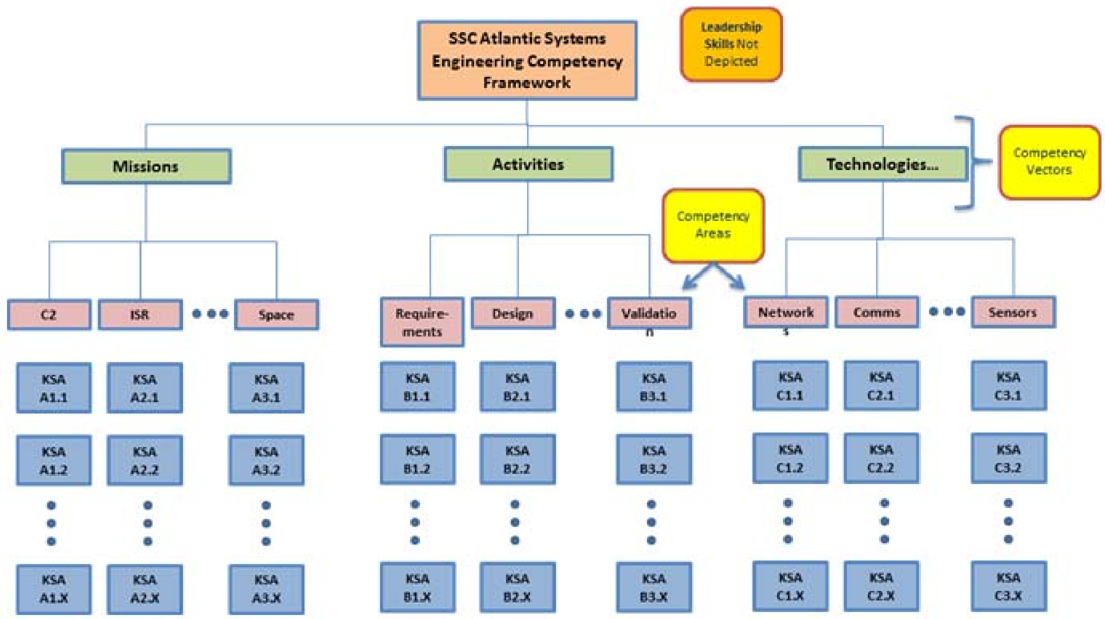


Figure 13. SSC Atlantic Systems Engineering Competency Framework

In order to define the associated competency development model (CDM) for any variant (or specialty, subrole) of a systems engineer role, one can simply choose which sets of KSAs most apply. In doing so, care must be taken not to choose too many KSAs so as not to make the process of *assessing* an individual against a CDM too time-consuming. The need to control the number of total KSAs for a given role's CDM was discussed in earlier in Chapter III—KSA Use Case 2. Figure 14 depicts a high level view of how KSAs in different competency areas may be mapped or assigned to a systems engineer's CDM.

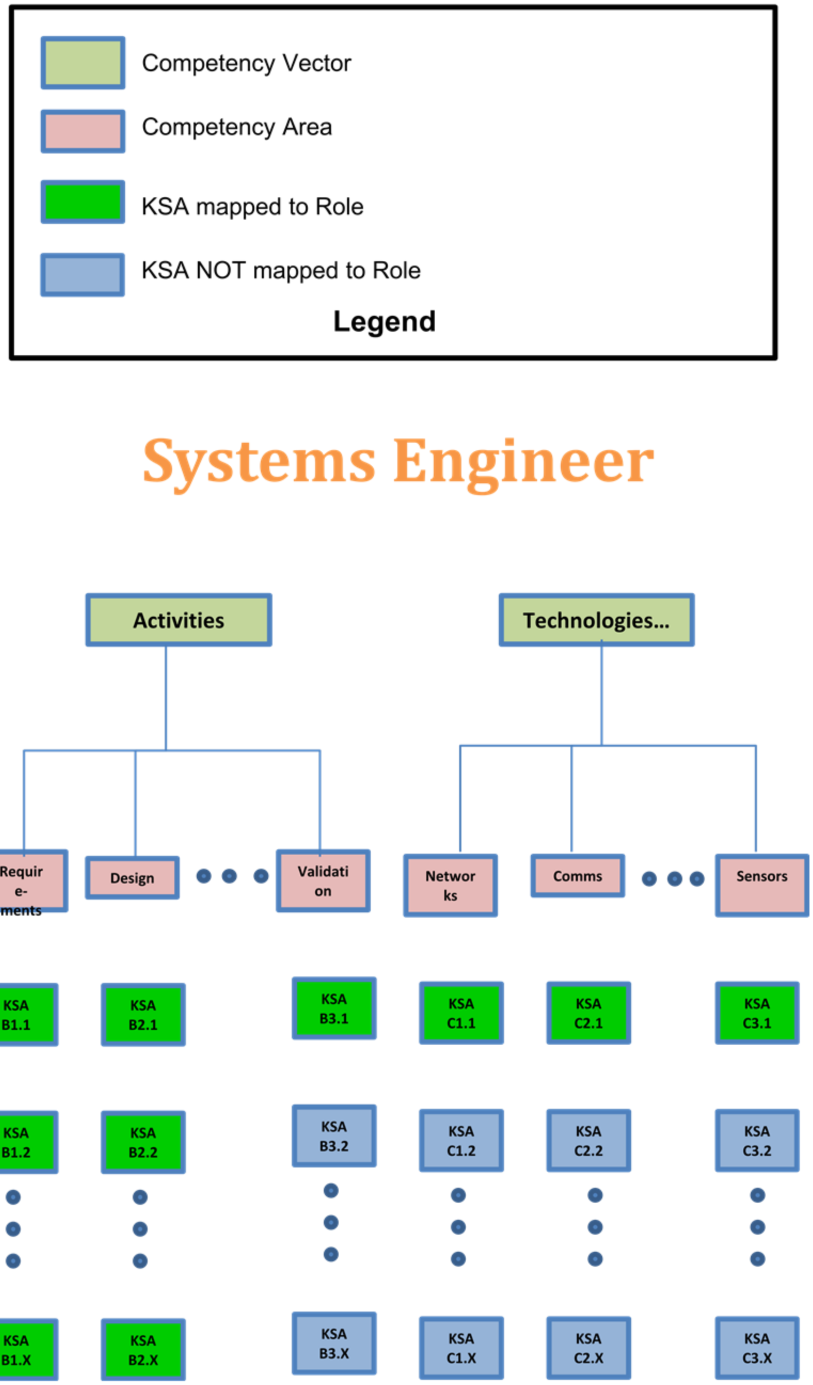


Figure 14. KSAs from Different Competency Areas Assigned to Systems Engineer CDM

B. SSC ATLANTIC ENGINEERING DEPARTMENT CORE KSAS

Before a determination can be made as to which KSAs should be common to all systems engineers, one must first determine which KSAs are common (or core) to all of

the SSC Atlantic Engineering Department. KSAs chosen as part of the “core” Engineering CDM would be included in every engineering department employee’s CDM. In April 2013, key members of the SSC Atlantic Engineering Department leadership reviewed over 4,000 KSAs to determine those that were core to all 2,000+ members of the engineering department at the entry and intermediate CDM stages. KSAs at the advanced and expert stages would be assumed to be only role-specific, where the role of a systems engineer is just one of many engineering department roles. A total of 11 representatives participated in the identification of these core KSAs across the following engineering divisions and departments: Net-centric Engineering and Integration; Computer Applications; Network and Communications; Intelligence, Surveillance, Reconnaissance (ISR) / Information Operations (IO); Space; Information Assurance; and Test, Evaluation & Certification. For each of the KSAs that could potentially be considered core to all of the SSC Atlantic Engineering Department’s overarching CDM, 10 of the 11 possible votes had to be affirmative. Of the 4,000+ KSAs identified as potential candidates, 62 were ultimately selected as common to all of the SSC Atlantic Engineering Department. Table 10 identifies these core engineering KSAs, their respective competency area and associated competency development stage.

Competency Vector	Competency Area	KSA	Stage
Activity	GENERAL	Basic knowledge of technical and technical mgt processes	Entry
Activity	GENERAL	Knowledge of engineering/technical artifacts required by SSC Atlantic	Entry
Activity	GENERAL	Ability to review engineering/technical artifacts for completeness and quality	Intermediate
Activity	1.0 TECHNICAL BA SIS FOR COST	Knowledge of SPAWAR accounting and financial systems	Entry
Activity	1.0 TECHNICAL BA SIS FOR COST	Ability to contribute to timely and accurate full cost budget information (such as labor, procurement, travel estimates) to project managers when requested	Entry
Activity	1.0 TECHNICAL BA SIS FOR COST	Ability to perform cost estimating on technical work products	Entry
Activity	1.0 TECHNICAL BA SIS FOR COST	Ability to use Work Breakdown Structure (WBS) as a tool for tracking actual vs. estimated costs and use this information to revise cost models appropriately	Entry
Activity	2.0 MODELING & SIMULATION	Knowledge of decision support tools, models, or simulations that are applicable to your job.	Entry
Activity	3.0 SAFETY ASSURANCE	Understand and comply with safety strategies, policies, and standards	Entry
Activity	3.0 SAFETY ASSURANCE	Understands the relationship between reliability, availability, maintainability and safety	Intermediate
Activity	4.0 STAKEHOLDER REQUIREMENTS DEFINITION	Able to identify major stakeholders	Entry
Activity	4.0 STAKEHOLDER REQUIREMENTS DEFINITION	Understand the importance of requirements traceability	Entry
Activity	4.0 STAKEHOLDER REQUIREMENTS DEFINITION	Can support the elicitation of requirements from stakeholders	Intermediate
Activity	5.0 REQUIREMENTS ANALYSIS	Understands that there are different types of requirements e.g. functional, non-functional, business etc.	Entry

Competency Vector	Competency Area	KSA	Stage
Activity	5.0 REQUIREMENTS ANALYSIS	Understands the importance of managing requirements throughout the lifecycle	Entry
Activity	5.0 REQUIREMENTS ANALYSIS	Understands the need for good quality requirements (achievable, verifiable, unambiguous, necessary and sufficient, complete, expressed as a need, consistent, and appropriate)	Entry
Activity	5.0 REQUIREMENTS ANALYSIS	Contribute to decomposition of requirements	Entry
Activity	5.0 REQUIREMENTS ANALYSIS	Contribute to development of specification documents	Entry
Activity	5.0 REQUIREMENTS ANALYSIS	Understands the relationship between design and requirements	Intermediate
Activity	5.0 REQUIREMENTS ANALYSIS	Ability to identify and analyze requirements	Intermediate
Activity	6.0 ARCHITECTUR E DESIGN	Basic knowledge of the different types of architecture	Entry
Activity	6.0 ARCHITECTUR E DESIGN	Identifies systems interfaces and interoperability concerns.	Entry
Activity	6.0 ARCHITECTUR E DESIGN	Understands the need to explore alternative and innovative ways of satisfying the system need	Entry
Activity	6.0 ARCHITECTUR E DESIGN	Knowledge of the principles of architectural design and its role within the lifecycle	Entry
Activity	6.0 ARCHITECTUR E DESIGN	Identify the basic elements/sections of an Technical Data Package (TDP)	Entry
Activity	10.0 VALIDATION	Understands the purpose of validation	Entry
Activity	10.0 VALIDATION	Understand structure and basic elements of a SOVT document	Entry
Activity	11.0 TRANSITION	Aware of the type of activities required for transition to operation	Entry
Activity	12.0 SYSTEM ASSU RANCE	Knowledge of Risk Management Framework (RMF)	Entry

Competency Vector	Competency Area	KSA	Stage
Activity	12.0 SYSTEM ASSU RANCE	Knowledge of information assurance principles and tenets (confidentiality, integrity, availability, authentication, non-repudiation).	Entry
Activity	15.0 TECHNICAL P LANNING	Basic knowledge of technical disciplines/specialties applicable to command	Entry
Activity	15.0 TECHNICAL P LANNING	Knowledge of the command's global WBS	Intermediate
Activity	15.0 TECHNICAL P LANNING	Able to tailor systems engineering processes to meet the needs of a specific project/program	Intermediate
Activity	15.0 TECHNICAL P LANNING	Understands the importance of planning, monitoring and controlling systems engineering activities	Entry
Activity	15.0 TECHNICAL P LANNING	Aware that common technical processes need to be planned	Entry
Activity	16.0 TECHNICAL A SSESSMENT	Able to (for a subsystem or simple project) monitor progress against plans	Intermediate
Activity	16.0 TECHNICAL A SSESSMENT	Identifies continuous process improvements that enhance processes, products, and service quality.	Entry
Activity	16.0 TECHNICAL A SSESSMENT	Aware of review types and their purposes	Entry
Activity	16.0 TECHNICAL A SSESSMENT	Aware of activities to prepare for technical assessments	Entry
Activity	17.0 CONFIGURAT ION MANAGEMEN T	Knowledge and basic abilities associated to perform configuration management activities	Entry
Activity	17.0 CONFIGURAT ION MANAGEMEN T	Aware of configuration change control	Entry
Activity	18.0 REQUIREMEN TS MANAGEMENT	Participate in (for a subsystem or simple project) documenting requirements in the proper format.	Intermediate
Activity	18.0 REQUIREMEN TS MANAGEMENT	Knowledge of the Engineering Change Proposal (ECP) review process	Entry
Activity	18.0 REQUIREMEN TS MANAGEMENT	Knowledge of requirements management process.	Entry

Competency Vector	Competency Area	KSA	Stage
Activity	19.0 RISK MANAG EMENT	Knowledge of and the ability to contribute to identification of risk, risk analysis, and risk monitoring	Entry
Activity	19.0 RISK MANAG EMENT	Assists in executing the risk mitigation plan to ensure successful project and program completion.	Entry
Activity	20.0 TECHNICAL DATA	Ability to document and present lessons learned	Entry
Activity	21.0 INTERFACE M ANAGEMENT	Understands the need for interface management and its impact on the integrity of the system solution	Entry
Activity	22.0 SOFTWARE ENGINEERING	Basic understanding of software engineering principles	Entry
Activity	23.0 ACQUISITION	Ability to develop a Performance Work Statement (PWS) / Statement of Objectives (SOO)	Intermediate
Activity	23.0 ACQUISITION	Provides information for the Performance Work Statement (PWS) / Statement of Objectives (SOO)	Entry
Activity	25.0 SYSTEM OF S YSTEMS	Understands that SoS capability needs impact the system development	Entry
Activity	30.0 SYSTEMS THINKING	Able to describe the systems engineering lifecycle processes that are in place on their program	Intermediate
Activity	30.0 SYSTEMS THINKING	Able to define system boundaries and external interfaces	Intermediate
Activity	30.0 SYSTEMS THINKING	Aware of the influence the system has on the enterprise	Entry
Activity	Data Engineering	Aware of data management and data storage concepts	Entry
Activity	Enterprise Architecture	Understand the purpose and value of using architectures for requirements documentation, systems planning and investment decisions	Entry
Activity	Enterprise Architecture	Knowledge of DoD enterprise architecture principles and reference models	Intermediate
Technology	Communications	Basic knowledge of the characteristics of different communications systems	Entry

Competency Vector	Competency Area	KSA	Stage
Technology	IT SERVICE MANAGEMENT	Awareness DoD and DON ITSM policies, guidance and core references	Entry
Technology	Networks	Knowledge of computer networking fundamentals	Entry
Mission	GENERAL	Basic understanding of all Mission Areas / Domains	Entry

Table 10. KSAs core to all members of SSC Atlantic Engineering Department

C. SSC ATLANTIC ENGINEERING ROLES

With common KSAs established for all members of the SSC Atlantic Engineering Department, attention can now be focused towards identifying the roles and subroles that can be performed by employees of the department. The role of a systems engineer is one of many roles that can be performed at SSC Atlantic. As of June 2013, SSC Atlantic had identified the following roles to be germane to the SSC Atlantic Engineering Department:

- Systems engineer
- Technical specialist
- Software professional
- Data professional
- IT service management specialist
- Tester
- Information assurance (IA) professional
- Mission specialist
- Architect (a.k.a. enterprise architect)

Each of the KSAs that are identified for a systems engineer may also be used for other roles as well. In other words, some KSAs may be unique to a particular role, whereas some KSAs may be common to multiple roles. Chapter IV, Section B highlighted an extreme case where certain KSAs were considered to be common to *all* roles and, therefore, core to all members of the SSC Atlantic Engineering Department. Figure 15 shows how the role of a tester may share some of the basic KSA requirements as that of a systems engineer; however, the tester role also stresses KSAs in the

competency area of validation that the basic systems engineer CDM would not include. Conversely, a systems engineer is expected to develop a deeper set of KSAs in the competency areas of requirements analysis and architecture design than the tester. A complete description of each of the roles identified above can be found in Appendix C: SSC Atlantic Engineering Department Role Descriptions.

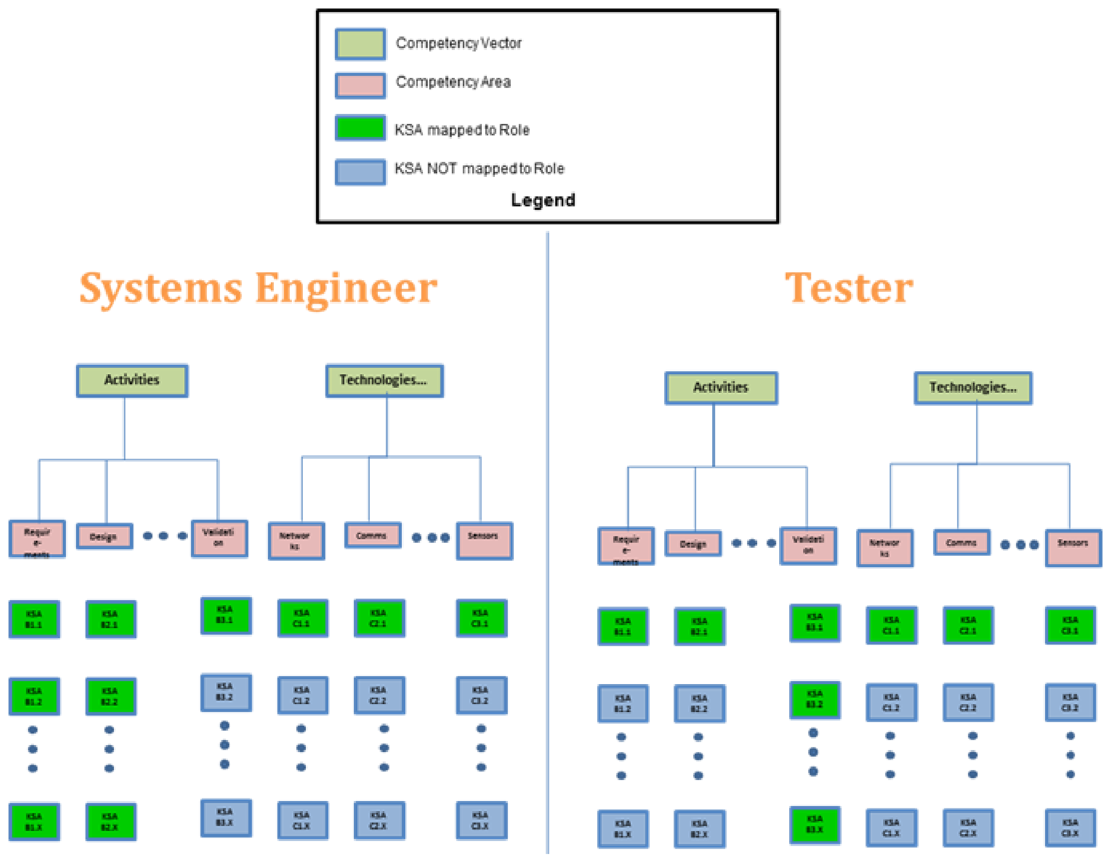


Figure 15. Mapping Roles to sets of KSAs—Comparing Systems Engineering Role to that of a Tester

D. SUBROLES OF THE SSC ATLANTIC SYSTEMS ENGINEER

Just as there are KSAs common to all members of the SSC Atlantic Engineering Department, there are also KSAs common to all Systems Engineers. In May 2013, SSC Atlantic systems engineer "role champions" (those responsible for defining the KSAs

associated with the systems engineer role) identified KSAs common to all systems engineers at various CDM stages. Table 11 depicts these core systems engineer KSAs by competency area.

Competency Vector	Competency Area	KSA	Stage
Activity	1.0 TECHNICAL BASIS FOR COST	Ability to contribute to a Project Management Plan (PMP)	Intermediate
Activity	1.0 TECHNICAL BASIS FOR COST	Ability to Review and approve cost estimates for subsystem elements.	Intermediate
Activity	5.0 REQUIREMENTS ANALYSIS	Understands the characteristics of quality requirements	Intermediate
Activity	5.0 REQUIREMENTS ANALYSIS	Prioritizes requirements for system upgrades and future enhancements with the sponsor/customers, key stakeholders, and end users	Advanced
Activity	6.0 ARCHITECTURE DESIGN	Facilitates agreements among multiple stakeholders to resolve system interfaces and interoperability concerns.	expert
Activity	16.0 TECHNICAL ASSESSMENT	Executes continuous process improvements that enhance processes, products, and service quality.	Intermediate
Activity	17.0 CONFIGURATION MANAGEMENT	Basic ability to use configuration management tools for configuration management	Entry
Activity	19.0 RISK MANAGEMENT	Knowledge of and the ability to contribute to development of risk mitigation/contingency action plans	Entry

Competency Vector	Competency Area	KSA	Stage
Activity	19.0 RISK MANAGEMENT	Able to perform risk analysis	Intermediate
Activity	23.0 ACQUISITION	Serve on Source Evaluation Board (SEB) or as a Contracting Officer's Representative (COR) and have experience with development and implementation of contracts, procurement of major hardware or software situations	Intermediate
Activity	30.0 SYSTEMS THINKING	Able to define technical problem scope	Intermediate

Table 11. KSAs Common to All Systems Engineers

There are a large number of project types for which a systems engineer at SSC Atlantic may be tasked to perform. Therefore, there are lots of different *types* of systems engineers. While there is a common set of KSAs associated with systems engineers, there are a number of KSAs that depend upon the subrole or specialty area of the systems engineer. Figure 16 defines the systems engineer subroles or specialty areas critical to the SSC Atlantic Engineering Department. Appendix D shows how role cards can be used to define and communicate each of the systems engineer subroles or specialty areas in terms of their basic role description/duties, key KSAs, typical employee job series, typical work products or deliverables, and recommended training.

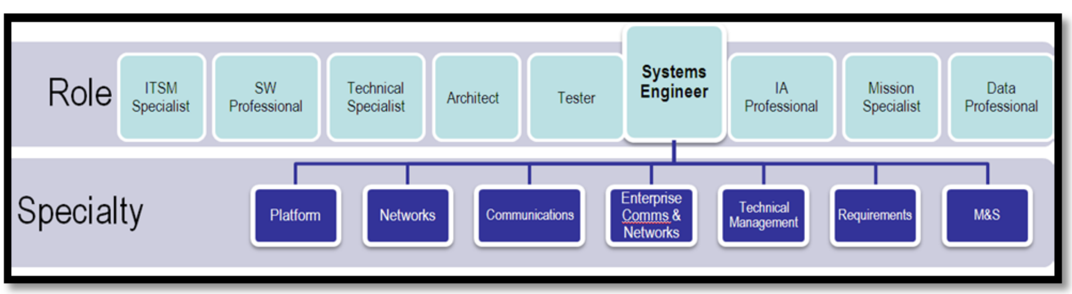


Figure 16. SSC Atlantic Engineering Department Roles / Subroles of Systems Engineer

E. SSC ATLANTIC SE USE CASES

An IPT at SSC Atlantic typically supports a number of related projects. IPTs are usually organized by common end item products and/or funding sponsors. For example, an IPT may focus entirely on wireless communications for the Navy, electronic security systems for the U.S. Marine Corps, or command center IT infrastructure for Joint services. The projects within an IPT may be highly correlated, where the end item product to be delivered by each project has a physical interface and interdependency with the products of the other projects. In this case, the IPT may even be delivering an integrated system of systems. In other cases, projects within an IPT are simply of a similar nature, but do not deliver interfacing end item products. In these cases, it is commonplace for an IPT to specialize in a family of systems that are routinely designed and delivered to multiple locations, but in similar configurations.

Given the astounding number of IPT formations, IT domains and variations in system (or end item product) complexity, it would be very difficult to create a framework that satisfies all potential systems engineering use cases in full. However, by generalizing most of SSC Atlantic's SE projects into five different use cases, one can understand some of the more common IPT perspectives on the role of a systems engineer. The following subsections examine these five use cases and some of their key competency areas. The figures provided with each of these use cases were developed in collaboration with John Lillard, SSC Atlantic Information Dominance Chief Architect. These images were used to help clarify various levels of abstraction in system complexity and SE project types.

1. SE Use Case 1—Subsystem or Component Engineering and Assessments

In this scenario, the project scope for an IPT would be to develop, procure or assess a new component or subsystem for use within a larger system. The engineering of the overall system is managed outside of the IPT's project scope. An example would be a biometrics IPT which is tasked to assess facial recognition technologies to determine which one will provide the highest quality solution to meet the customer's needs at the

best value to the government. Key competency areas associated with this use case include decision analysis as well as any number of competency areas within the technology competency vector (for example, sensors.)

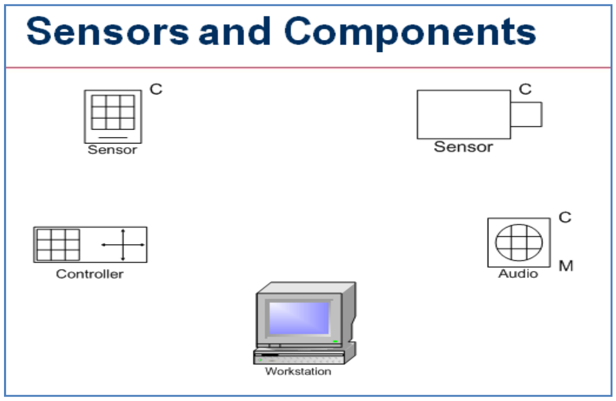


Figure 17. SE Use Case 1—Subsystem or Component Engineering and Assessments

2. SE Use Case 2—Systems Engineering (Simple System)

In this scenario, an SSC Atlantic IPT would be tasked to develop and/or integrate a new capability in the form of a system, which is comprised of commercial-off-the-shelf (COTS) and/or government-off-the-shelf (GOTS) components integrated into a single capability. This type of system is typically used by a single organization or single mission. Key competency areas for this use case include stakeholder requirements definition, architecture design, verification and transition.

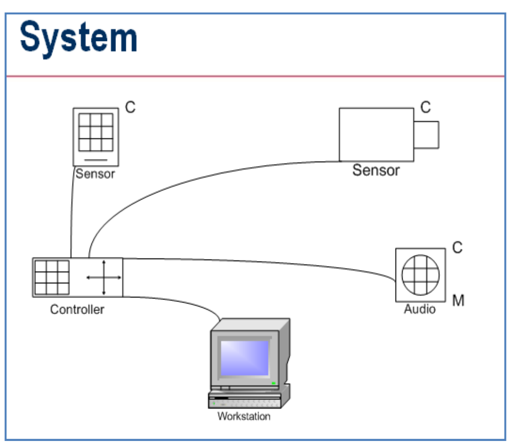


Figure 18. SE Use Case 2—Systems Engineering (Simple System)

3. SE Use Case 3—Complex Systems Engineering

Oftentimes, SSC Atlantic is tasked with fulfilling a customer capability gap that is more complex in nature and the basic problem at hand has not been solved in the past. In this case, SSC Atlantic may be tasked with developing and/or integrating a new capability in the form of a system. The scale of the system, its functions and interactions along with the diversity of the user base elevate the complexity of the effort. The resulting system is comprised of COTS and or GOTS components integrated into a large, multifunction capability. Key competency areas associated with complex systems engineering include requirements management, risk management, interface management, and integration.

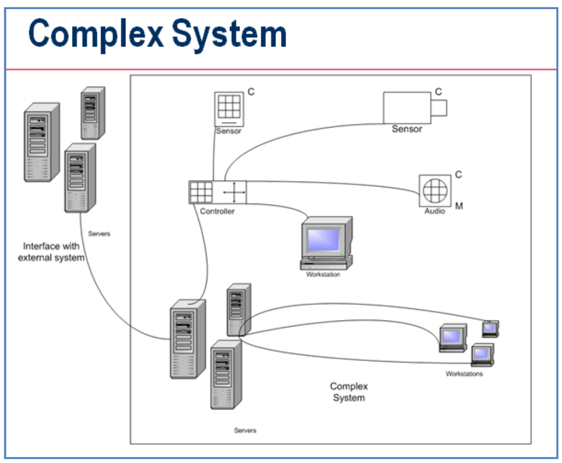


Figure 19. SE Use Case 3—Complex Systems Engineering

System complexity plays a key role in delineating between SE Use Case 2 and 3. Table 11 depicts the key differences between basic or simple systems engineering and complex systems engineering as they apply to SSC Atlantic IT projects.

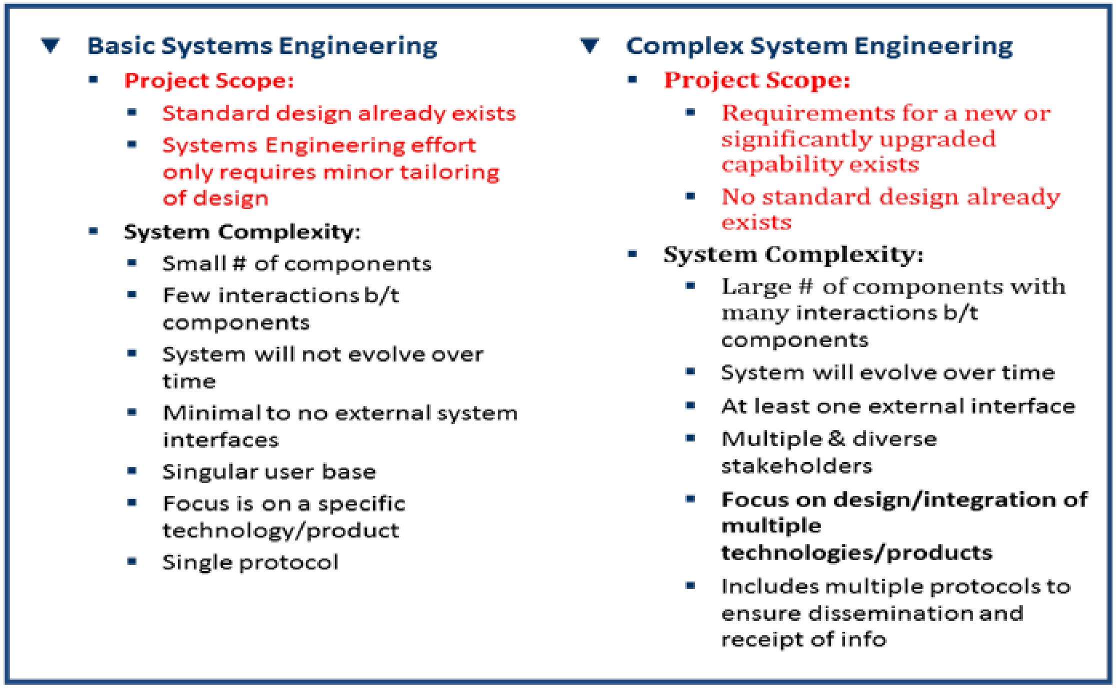


Figure 20. Comparison of Basic (Simple) SE and Complex SE

4. SE Use Case 4—Platform Systems Engineering

The SE use case for *platform* systems engineering focuses on the integration of systems into physical platforms to ensure that environmental, mounting, heat, power, lighting, network infrastructure, safety, ergonomics and/or survivability requirements are met. Physical platforms may include vehicles, ships, submarines, buildings, command centers and other physical structures in which IT systems and infrastructure may be integrated. This use case stresses the conduct of site or platform surveys (part of technical assessment), technical data package development (part of architecture design), technical planning, integration, validation and safety assurance.

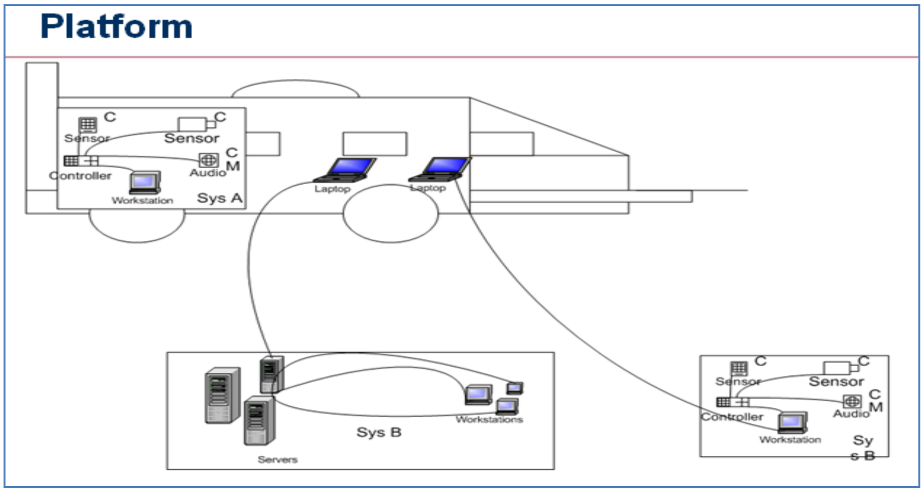


Figure 21. SE Use Case 4—Platform Systems Engineering

5. SE Use Case 5—Systems of Systems (SoS) Engineering

Some of the IPT efforts at SSC Atlantic are more focused on the methodology of systems of systems engineering rather than on the life cycle processes of conventional systems engineering. SoS engineering focuses on the planning, analyzing, organizing, and integrating of capabilities from a mix of existing and new IT systems into an SoS capability greater than the sum of the capabilities of the constituent parts. In addition to the tenets of traditional systems engineering, SoS engineering manages the complexity created by the cost, schedule and performance interdependencies of multiple independent programs that comprise the SoS. SoS engineering efforts are heavily grounded in the competency areas of systems thinking, enterprise architecture, interface management, risk management and, of course, SoS engineering.

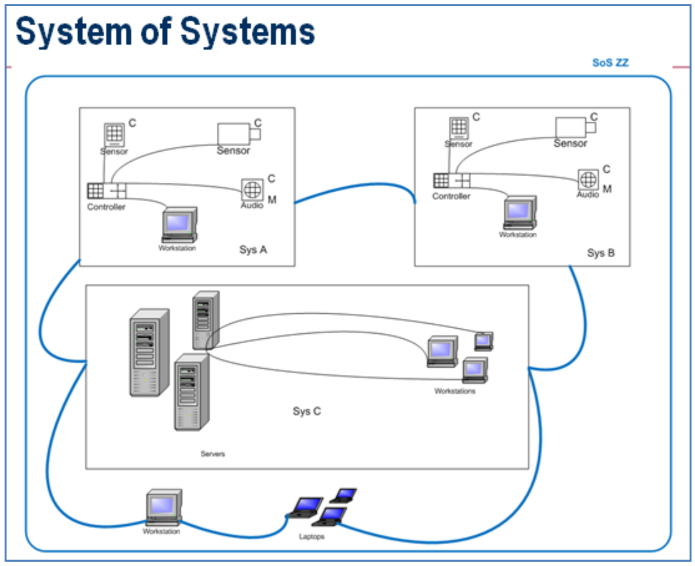


Figure 22. SE Use Case 5—Systems of Systems Engineering

F. COMPETENCY DEVELOPMENT AND ITS RELATIONSHIP TO SYSTEM COMPLEXITY

Over the course of his or her career, a systems engineer will likely encounter projects that span more than one of the SE use cases described in Chapter IV, Section E. For example, a systems engineer may start out researching and assessing various IT components, then take on an assignment as a project engineer for a simple system, then grow into the role of a lead systems engineer for a complex system, and so forth. Generally speaking, a systems engineer will be assigned tasking that increases in system complexity over time. Not coincidentally, a systems engineer will develop KSAs across higher proficiency or developmental levels. This increase in competency and increased responsibility with more complex systems and projects go hand in hand. Figure 23 from *Building a Competency Taxonomy to Guide Experience Acceleration of Lead Program Systems Engineers* illustrates the notional progress a systems engineer would exhibit over the course of his or her career in terms of increased proficiency/competency and the responsibility of addressing situations and systems of increasing complexity.

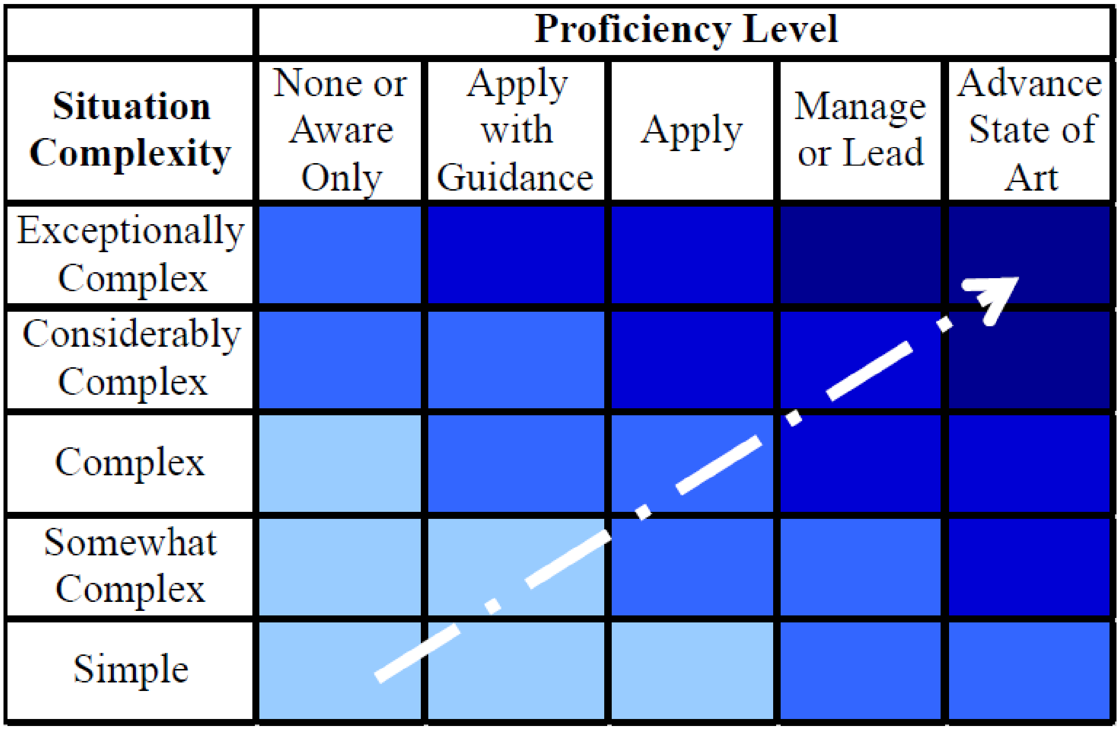


Figure 23. Proficiency Level and Situational Complexity (From Squires et al., 2011, p. 7)

Chapter IV, Section D defined several subroles for the role of a systems engineer. Each of these subroles bears its own set of KSAs at various proficiency stages and therefore, its own competency development model. Figure 24 depicts competency development progression for four subroles of the SE role—platform, communications, networks and technical management. This figure was developed in collaboration with John Lillard (SSC Atlantic) in order to illustrate how a SE competency development model provides a developmental roadmap for systems engineers in terms of competency/proficiency progression, increased project or system complexity and increased leadership responsibility.

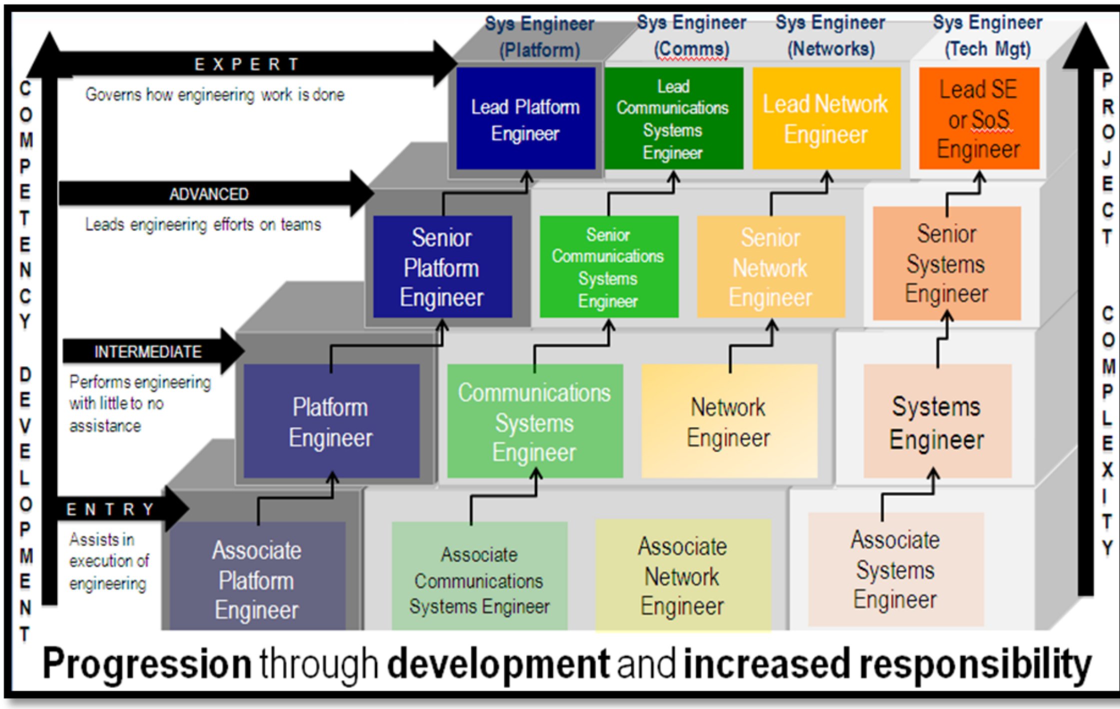


Figure 24. Competency Development / Proficiency Progression for Sub-roles of a Systems Engineer

V. A MODEL FOR EFFECTIVE SYSTEMS ENGINEERING WORKFORCE DEVELOPMENT AT SSC ATLANTIC

A. EMPLOYING COMPETENCY DEVELOPMENT MODELS

Defining the competency areas and KSAs required for SSC Atlantic systems engineers at various competency development levels and different use cases explains *what* types of KSAs need to be developed. However, if a systems engineer determines that he or she has a gap in KSAs in order to achieve his or her goals, then the competency framework can only tell them *what* the systems engineer is missing. In order to adequately employ a competency development model, one must recommend *how* KSAs can or even should be obtained.

According to the naval SE CDM, KSAs can principally be obtained through the following developmental methods:

- Education—Learned in a classroom environment as part of undergraduate, graduate or certificate programs
- On the job training—Learned on the job
- Professional development—Workshops or training sessions accomplished within an organization

Using the basic KSA development methods defined by the naval SE CDM, four primary methods can be applied to SSC Atlantic:

- Defense Acquisition University courses (educational training)
- Graduate or certificate program (educational training)
- SSC Atlantic-developed and provided training courses and/or workshops (professional development)
- On the job training

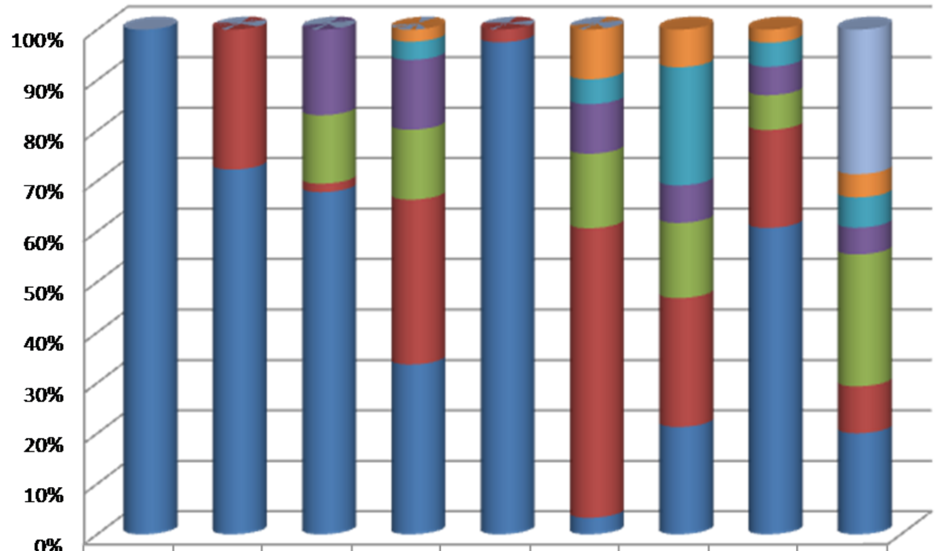
In an Internet post entitled "Education versus Training," Geetha Krishnan (2008) makes the following assertions that help differentiate education (educational training) from training (professional development):

> Education emphasizes first principles; training emphasizes application.
>
> Education focuses on building the mind; training on building skills.
>
> Most training is communication; hence the pizzazz. Presentation style is more important than instructional rigor. Education, for the most part (refer the parenthetical point on the social act above), is content-driven.
>
> Most training is company-specific; hence, not easily transferable from one job to another. Most education would be transferable.
>
> The learner for both education and training could be unwilling. But the learner for training is allowed to voice his thoughts and get the training / trainer changed. The onus of making training succeed is on the trainer or the organization; in education the learner takes a higher responsibility. As a corollary, if you don't do well in education, you fail; if you don't do well in training, the training failed (Krishnan, 2008).

Each of these assertions may be, in fact, matters of Krishnan's opinion; however, when the term "education" is replaced with "educational training" meaning undergraduate, graduate or certificate programs, then many analogies can be made. For example, SE graduate degree programs and the Certified Systems Engineering Professional (CSEP) certification emphasize the principles, focus on SE process life cycle content, and are transferable to a wide range of Industry and DoD organizations. When the term "training" is replaced with "professional development" or training/workshops accomplished within an organization such as SSC Atlantic, then similar analogies can be made. Generally speaking, SSC Atlantic-developed and delivered SE training is organization-specific, is not as easily transferable from one organization to another, emphasizes the *application* of SE principles, and generally offers a more dynamic opportunity for feedback to the training instructor who is likely a practicing systems engineer moonlighting as a trainer.

B. THE ROLE OF DEFENSE ACQUISITION UNIVERSITY IN SE WORKFORCE DEVELOPMENT

Most systems engineers at SSC Atlantic are either designated as being in a Defense Acquisition Workforce Improvement Act (DAWIA) Systems Planning, Research, Development and Engineering (SPRDE)-SE billet or have at least taken some of the associated DAU classes covered by the SPRDE-SE curriculum. The SPRDE-SE classes are a combination of computer-based and instructor-led training. Figure 25 shows a breakdown of the primary SPRDE-SE classes and the percentage of the learning objectives associated with each level of Bloom's taxonomy (discussed in Chapter III). In this case, learning objectives are directly correlated to the KSAs that are targeted to be developed by each class. The far right column of Figure 25 shows what percentage of the naval SE CDM (shown here as the NPS SE COMP MOD) KSAs are associated with each level of Bloom's taxonomy as well. Figure 25 illustrates that, in general, DAU covers the knowledge and comprehension levels of Bloom's taxonomy sufficiently. Therefore, for KSAs that are associated with basic DoD-generic (as opposed to SSC Atlantic-specific) knowledge and comprehension, it makes sense for DAU training to be the preferred KSA development method.



	ACQ101	SYS101	ACQ201A	ACQ201B	SYS202	SYS203	SYS302	SPRDE-SE Totals	NPS SE COMP MOD
affective	0	0	0	0	0	0	0	0	29%
evaluation	0%	0%	0%	2%	0%	10%	7%	3%	5%
synthesis	0%	0%	0%	3%	0%	5%	23%	5%	6%
analysis	0%	0%	17%	13%	0%	10%	7%	6%	5%
application	0%	0%	14%	13%	0%	15%	15%	7%	26%
comprehension	0%	28%	2%	31%	3%	57%	26%	19%	9%
knowledge	100%	72%	68%	32%	98%	3%	21%	61%	20%

Figure 25. Cognitive Levels of DAU SPRDE-SE Level III Curriculum and NPS SE Competency Model (From Alexander, 2013, p. 42)

It would be insufficient to look solely at the level of Bloom's taxonomy when assessing the applicability of DAU classes to SE KSAs. One must also analyze the respective competency areas emphasized in the DAU SPRDE-SE classes to determine which are adequately addressed and which are not. Figure 26 depicts the number of DAU SPRDE-SE continuous learning/performance objectives (CL/POs) associated with each SE competency area. It should be noted that the competency areas of acquisition and risk management are appropriately covered by SPRDE-SE. In fact, Juli Alexander observes, "the DAU SPRDE-SE training curriculum is robust with regard to acquisition training. Approximately a third of the curriculum focuses on this essential competency" (2013, p. xvi). Technical planning in a broad sense is sufficiently covered as well, but

likely requires tailoring to show how it should be accomplished within an organization such as SSC Atlantic. Alexander also points out that the competency areas for safety assurance, system assurance, systems of systems, problem solving and strategic thinking show no "evidence of a strong link between the curriculum and the competency model… This would strongly demonstrate that the competencies in the model are not being addressed by the DAU SPRDE training curriculum" (2013, p. 53). It should also be noted that neither the technology nor the mission competency vectors are covered in SPRDE-SE. That being said, DAU offers a variety of SE classes in areas such as systems of systems, system assurance and other SE competency areas that are available DoD-wide but simply not included as part of the SPRDE-SE career track.

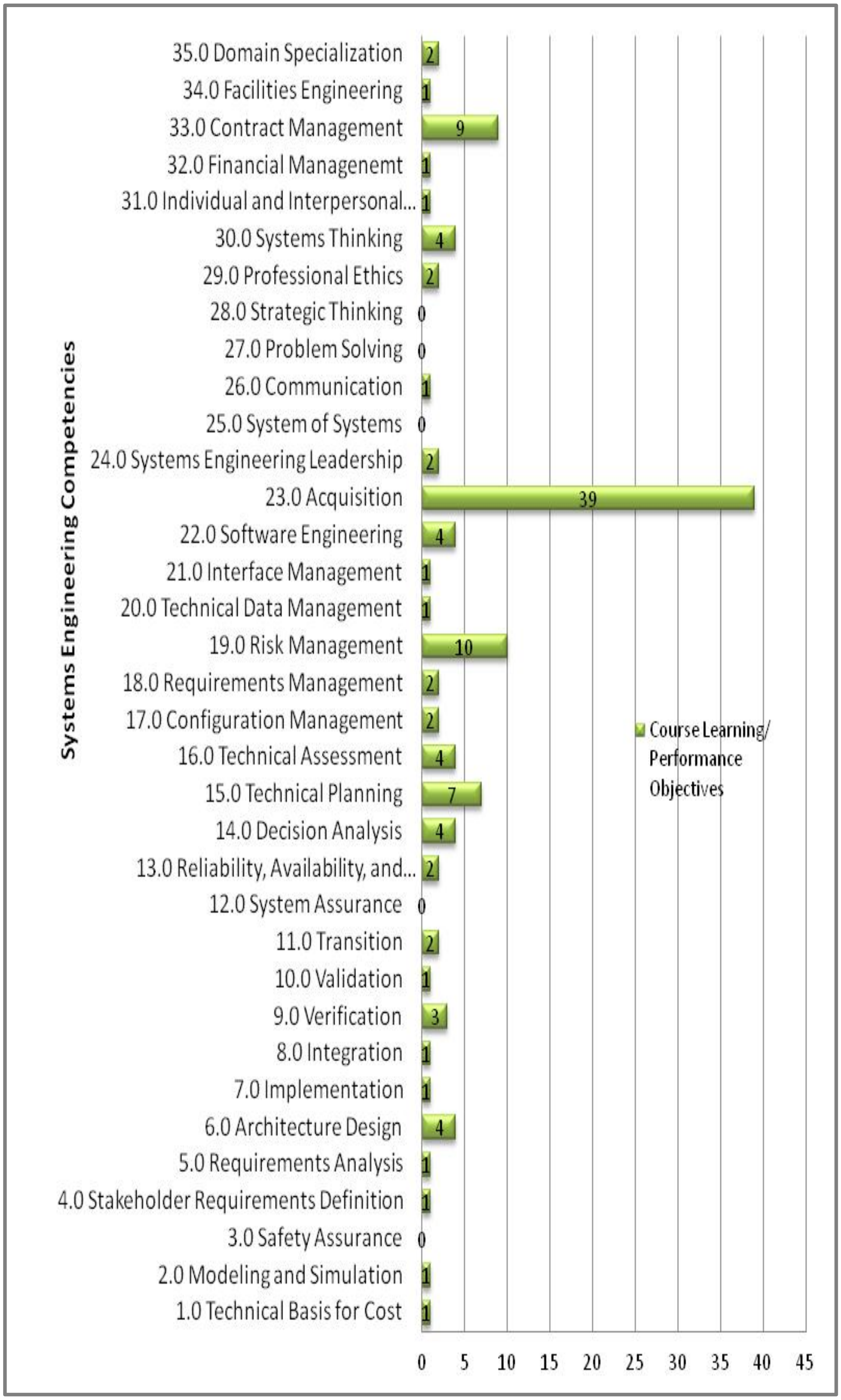


Figure 26. Number of DAU SPRDE-SE CL/POs in Each Systems Engineering Competency (From Alexander, 2013, p. 46)

C. IN-HOUSE SE TRAINING CURRICULUM DEVELOPMENT

When it comes to optimal methods for KSA development, the SEBoK states that, "traditionally, SE competencies have been developed primarily through experience, but recently, education and training have taken on a much greater role" (Pyster et al., 2012, p. 694). DAU provides SE and acquisition training to all of the DoD; therefore, much of the associated course material must be tailored for implementation at each DoD organization such as SSC Atlantic. For example, a SPRDE-SE class may provide the participant with knowledge regarding the key attributes of a sound requirement. However, that class will not specify which requirements management tools are to be used by the individual organizations, nor how specific requirements should be captured or documented. There are many cases such as this where the organization performing the work must develop or tailor its own SE classes in order to train the workforce on just *how* to execute these processes in a consistent manner. Systems engineers should also be educated on the specific SE tools used by their individual organizations. Examples of such tools include those associated with configuration management, risk management, requirements management and architecture design.

The other major gap between what DAU has to offer and the SSC Atlantic competency framework KSAs lies in the technology competency areas. Since SSC Atlantic is an IT-centric command, networks, software applications, sensors and other technology areas must be well understood by its systems engineers. This training gap also points to the need to provide command-specific training. In the SSC Atlantic networks and communications department, senior leaders have already begun developing "Network University" classes in order to educate systems engineers (with a networks subrole/specialty) on the basics of Navy network architecture design.

So how does one go about developing an "in-house" SE curriculum to address workforce/KSA development needs? GRCSE provides a process script for developing a curriculum for any competency, as shown in Table 12. From the steps highlighted in Table 12, a tailored SE curriculum development process for SSC Atlantic can be established. This approach would be considered a holistic approach to SE curriculum development.

1. Holistic Approach to SE Curriculum Development

- Step 1: Establish SSC Atlantic SE competency framework (the analysis of existing competency models, prioritization of relevant competencies/KSAs, and defining proficiency levels/stages from Table 12 Step 2)
- Step 2: Prepare outcomes and objectives that align to the SSC Atlantic engineering process framework (this step tailored from Table 12 Step 3 Bullet 1)
- Step 3: Use outcomes and objectives to prepare SE curriculum in 4 basic modules:
  - Technical Management
  - System Design
  - Product Realization
  - Technologies & Missions

Process Step	Description
Step 1: Establish the Development Team	• Identify program stakeholders • Form team from stakeholders such as faculty responsible for curriculum design and representatives from prospective employing organizations. • Use a wide group of reviewers for each stage of development.
Step 2: Create Competency Model	• Study and analyze various competency models. • Choose or adapt competencies appropriate to the stakeholders. • Define proficiency levels. • Select target proficiency levels for each competency.
Step 3: Prepare Draft Curriculum	• Based on competency model, prepare draft outcomes and objectives. • Use outcomes and objectives to prepare a draft curriculum.
Step 4: Assess Draft Curriculum against Competency Model	• For each competency, identify where in the curriculum it is addressed and assess its summative proficiency level. • Aggregate and report on gaps between the "as is" and "to be" proficiency levels. Also, report on problems with the competency model (e.g., imprecise descriptions of proficiency levels).
Step 5: Evolve Curriculum and Competency Model	• Based on the competency assessment report, identify curriculum elements that appear weak (e.g., entrance expectations, outcomes, objectives, curriculum architecture, the CorBoK, or individual course activities. • Determine required changes in the curriculum and implement them. • Modify the competency model based on the competency assessment report. • Repeat steps 4 and 5 after implementation to ensure continual evolution and improvement of the curriculum.

Figure 27. Process Script for Competency-based Curriculum Development. (From GRCSE v1.0, 2012, p. 109)

Taking a holistic or “top-down” approach can be effective in ensuring the breadth of competency area and KSA coverage in an in-house SE curriculum. However, the voice of the systems engineering workforce must also be truly heard in order to for the training strategy to be optimally effective. Once a holistic SE curriculum development strategy is established as summarized above, then a more grassroots approach should be taken to truly understand where SE skills have the greatest gap between supply and demand.

2. Bottom-Up Approach to SE Curriculum Development

- Step 1: Observe where employees lack knowledge of SE competency areas
- Step 2: Generate training concepts to fill gaps
- Step 3: Survey workforce to determine where training is most needed
- Step 4: Research what classes DAU, SSC Pacific and others have to offer
- Step 5: Decide which training classes need to be developed or tailored
- Step 6: Use various SE forums, blogs and wikis to shape class learning objectives with participation from the SE workforce
- Step 7: Recruit coalition of the willing and capable to develop and deliver training
- Step 8: Pilot training class exercises and draft training material via informal forum events
- Step 9: Develop final training content and aids (templates, checklists, process models)
- Step 10: The willing and capable deliver training (then obtain feedback and recalibrate)

When developing and delivering in-house training classes, here are a few training tips that have proven effective when delivering basic SE training classes at SSC Atlantic:

- Digital response technology using radio frequency (RF) clickers can be used to gage audience understanding of key concepts throughout the class. Questions should be challenging and generate thoughtful discussion on key concepts.
- Well-tailored individual and group exercises should be leveraged to ensure employees know how to apply key concepts.

- Defense Connect Online or other means of web-conferencing should be used to promote remote participation, collaborative exercises, polling, file sharing and class recordings.
- “Easy” slides can be included in the training material to help employees gain course credit and professional development units or continuous learning points for continuing education.

One final recommendation for the development and delivery of SE training courses is that the actual trainers should be practicing systems engineers themselves. Benefits of SE leaders developing SE course content and performing as SE trainers include the following:

- Promotes knowledge sharing and collaboration
- Provides ample opportunities for natural leaders to step up
- Allows trainers to gain double continuous learning points (CLPs)
- Typically results in cost savings over vendor-provided training
- Tailors training classes toward “how SSC Atlantic does it”
- Enables government control over course material
- Sets distinct expectations for the audience that can be enforced by SE management
- Promotes environment of continual learning
- Enables rapid delivery of emergent processes and techniques
- Allows trainers to truly master topics by teaching them

D. DEVELOPING KSAS THROUGH OJT AND FORMAL EDUCATION

Arguably, the best way to learn or develop KSAs is by *doing*. For that reason, OJT is ideal when it is possible and consists of a more knowledgeable, skilled and experienced systems engineer walking a less developed systems engineer through the execution of actual systems engineering. For this reason, SSC Atlantic has established formalized programs to encourage this type of knowledge transfer. During their first two years of employment at SSC Atlantic, junior systems engineers entering the workforce are encouraged to participate in rotational assignments on the order of three to six months, and these are designed to allow them to learn from more experienced systems engineers as well as provide worthwhile contributions to the associated projects and IPTs

More recently, SSC Atlantic has also started a job-shadowing program in which employees (not just systems engineers) can elect to shadow another senior employee for up to 16 hours in order for them to see how that individual approaches his or her job. This allows for employees at any point in their career to catch a glimpse at what it takes to perform in other positions within the organization as well as to get a better feel for which types of positions/jobs they might want to pursue later in their careers. They may also find that their "dream job" is not what they truly desire and thus allows them to more quickly adjust career goals to where their true passions can better align with organizational needs.

A postgraduate degree in SE can significantly increase SE an individual's competency level. Assuming that the employing organization will pay for at least a significant portion of the postgraduate degree cost, there are many factors to consider when an organization chooses to make such an investment. Typical SE Master's degree program costs are in the $20,000 to $50,000 range, but can certainly cost significantly more or a little less. Without question, cost should be a major driving factor for an organization choosing to invest in a postgraduate degree program as there would be an advantage in affording to send two individuals through a degree program rather than one. The use of a cohort, in which several individuals from the same organization participate in the same degree program for a reduced cost, should also be encouraged. Cohorts also offer students/employees an opportunity to collaborate with one another within the same organization, which can add value and support to their experiences. In some cases, cohorts offer an additional opportunity for an organization such as SSC Atlantic (or its Echelon III parent command—Space and Naval Warfare Command) the opportunity to more significantly influence the scope of the classes offered in the program and/or the case study or thesis topics available to the students.

Other critical factors influencing the selection of a SE degree program include scope and timing. A SE degree program should be selected which applies most directly to the scope of SE work being conducted within the organization as well as by the participating employees. In the case of SSC Atlantic, a degree program which features a focus on IT and naval systems would be more valuable than one that does not emphasize

these core elements of SSC Atlantic's mission. Another critical factor for SE degree program selection is *when* the individual embarks on this effort during their career. GRCSE states, "Whether the student obtains work experience between completing a bachelor's program and commencing master's level studies is one of the most important factors in professional master's level study" (GRCSE, 2012, p. 5). With respect to practicing systems engineers in the US and in Europe, GRCSE also points out that, "Few obtain an undergraduate SE degree or study SE for their first master's degree" (GRCSE, 2012, p. 5). GRCSE goes on to recommend that at least two years of professional experience be obtained prior to pursuit of a master's degree in SE. SSC Atlantic typically requires five years of professional experience as well as achievement of the target DAWIA certification level (for those in a DAWIA billet) prior to pursuit of a postgraduate degree funded by the organization. Other considerations for matching individuals with postgraduate SE degrees include the individual's likelihood of remaining in the organization for a significant period of time, probability of the individual actually completing the graduate degree program, and the probability that the individual will actually apply what is learned to current and future projects.

E. OTHER FORMS OF WORKFORCE DEVELOPMENT AND THE DEVELOPMENT OF LEADERSHIP SKILLS

Job shadowing and rotational opportunities are two of the many opportunities for competency development within SSC Atlantic. When it comes to developing leadership skills such as external awareness, interpersonal skills and team building, programs such as the SSC Atlantic Mentorship Program and the Mid-Career Leadership Program (MCLP) can be very effective. The Mentorship Program offers a variety of different mentor-mentee engagement constructs—group mentoring (two mentors and eight mentees interacting at once), speed-mentoring (much like speed-dating) and classical one-on-one mentoring. As of July 2013, the Mentorship Program is in its second iteration of existence and continues to improve by providing a loosely-structured, yet objective-driven roadmap to fostering mentor-mentee relationships. The Mentorship Program is completely voluntary and allows mentor-mentee relationships to take form naturally.

The MCLP offers a much more intensive and structured learning environment for SSC Atlantic employees and, thus, it is much more competitive and time-consuming. The program lasts six months and only admits 20 participants each round. While the MCLP does not guarantee promotion, graduates are prepared to assume greater leadership roles and responsibilities. Many of the leadership skills highlighted in the SSC Atlantic competency framework are either directly or indirectly addressed by the program.

F. IDENTIFYING WORKFORCE DEVELOPMENT METHODS FOR EACH KSA

Figure 28 provides a decision tree which provides a recommended development method for different types of systems engineer KSAs. Although no distinction was made between *basic* and *advanced* in-house training, the assumption is that a basic in-house training session on a given competency area or set of KSAs would last four to eight hours with simple exercises, while a more advanced in-house training session would generally last forty hours or longer and would include more extensive "real-world" exercises. Appendix E provides recommended KSA development methods for each of the KSAs identified for a systems engineer. The leadership skills are excluded from this table, but are included in Appendix B.

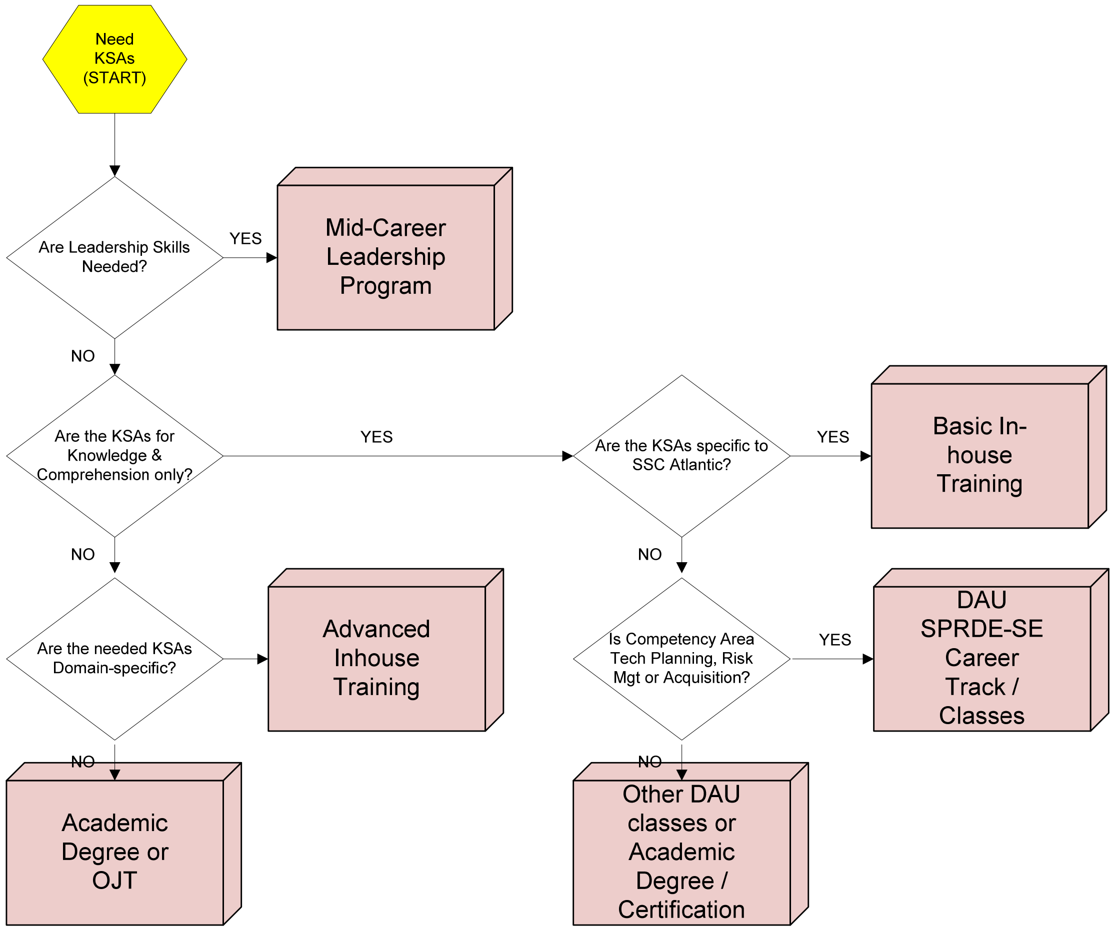


Figure 28. Decision Tree for Determining Which Developmental Method Should Be Used for Different Types of KSAs

G. ASSESSING A SYSTEMS ENGINEER'S COMPETENCY LEVEL

There are a variety of ways to assess whether a systems engineer has actually developed or attained a particular knowledge, skill or ability. The same can be said for assessment methods used as exit criteria for passing SE courses, since the intent of a SE course is to develop the KSAs of the participants. Some KSA assessment methods are very basic, easy to measure and only provide limited insight into the systems engineer's true competency, such as the use of multiple-choice tests. Other assessment methods such as case study projects, oral exams or written essays are typically more labor-intensive and more subjective, yet offer additional insight into an individual's depth of KSAs. GRCSE Appendix E provides a more exhaustive look into conducting an

assessment of SE KSAs and course learning objectives (GRCSE, 2012, p. 97). As of July 2013, a proposal has been set forth to adopt a common competency development model assessment process across all of SSC Atlantic. This competency assessment process consists of individual's assessing themselves against their role's competency development model (CDM), submitting their CDM self-assessment and requested development/proficiency stage for official review, and a competency assessment board making the determination as to whether or not the individual has or has not achieved their asserted development/proficiency stage. If the board determines that the individual has not achieved their desired stage, then the board provides feedback to the employee as to which KSAs require additional development and basic recommendations on how to do so. Figure 29 depicts the proposed SSC Atlantic competency level assessment process as illustrated by Ann Rideout, Deputy Competency Lead for the SSC Atlantic Networks and Communications Engineering Department.

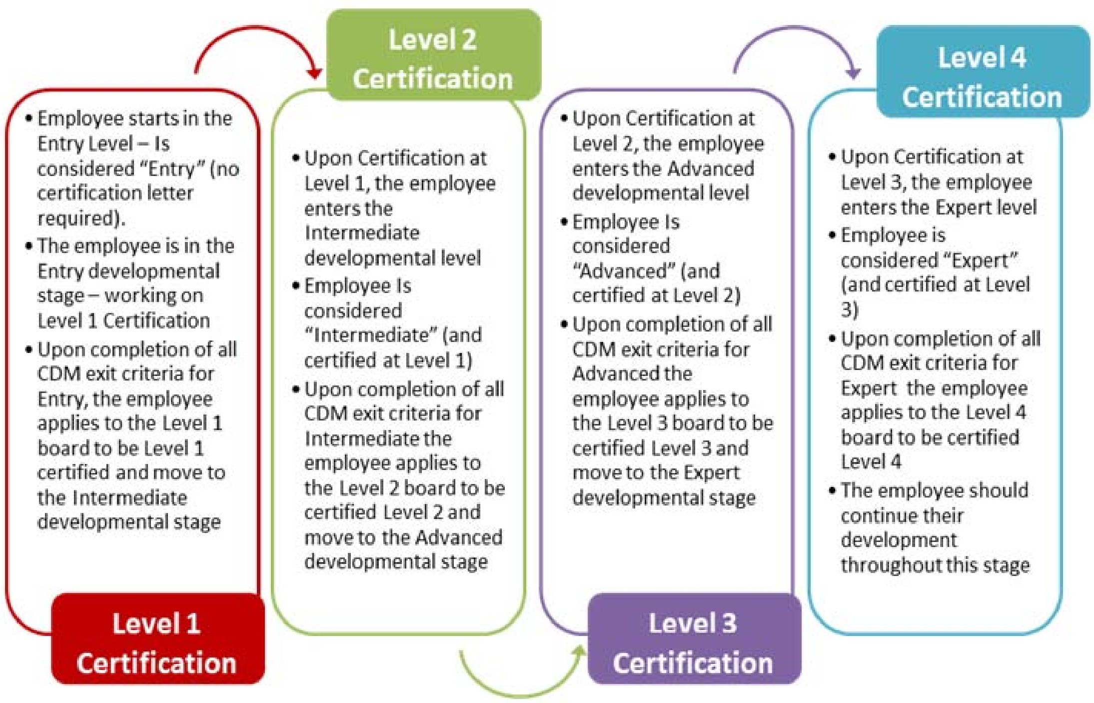


Figure 29. Competency Level Assessment Process

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VI. CONCLUSION AND RECOMMENDATIONS

A. FINDINGS

Research question 1 asks what competency areas and associated KSAs are particularly applicable to SSC Atlantic systems engineers. In order to organize competency areas and KSAs into logical groupings, four competency vectors were established as depicted in Figure 12. Competency areas could then be defined and grouped under each competency vector. Each competency area could then be prioritized based on a standard set of SE use cases most commonly experienced at SSC Atlantic, as well as based on DoD and industry standards, as shown in Table 9. The high prioritization of competency areas associated with requirements, architecture design, software engineering and system assurance highlights the importance for sound up-front systems engineering process execution, IT systems' increasing reliance on software and the paramount need for cybersecurity. As far as applicable KSAs within each competency area are concerned, Table 10 identifies KSAs core to the SSC Atlantic engineering department while Table 11 depicts the basic KSAs common to all systems engineers. By defining subroles (or specialty areas) for a systems engineer, further KSAs can be defined that stress certain competency areas over others. Figure 16 depicts example specialty areas associated with the systems engineer role.

Research question 2 asks how GRCSE can be used to effectively employ a CDM. GRCSE provides a process script for competency-based curriculum development, as shown in Figure 27 from GRCSE v1.0. Chapter V, Section C of this thesis describes how SE curriculum development should optimally be accomplished by taking both a holistic (top-down) approach—tailored from GRCSE's process script—as well as a bottom-up approach. The GRCSE-based top-down approach can be effective in training to the breadth of competency area and KSA coverage desired in a SE curriculum. A bottom-up approach can be effective in ensuring that the voice of the employee (the systems engineer in this case) is adequately heard as well and ultimately considered when establishing the SE training curriculum.

Research question 3 asks how various forms of education and training can best support the development of KSAs required to develop competent systems engineers at SSC Atlantic. Chapter V explores various forms of education and training that can be used to develop systems engineers, or in other words, train systems engineers on the KSAs needed in their CDM. Figure 28 provides a simple decision tree for determining when various forms of education and training may typically be most effective for developing KSAs in different competency areas or at different levels of Bloom's taxonomy. Table 17 provides recommended development (or education and training) methods for each KSA defined in an SSC Atlantic systems engineer's CDM.

B. CONCLUSION

In order to properly develop a SE workforce in an IT command such as SSC Atlantic, one must first understand *what* competency areas and KSAs systems engineers must attain. A SE competency framework should consider the SE life cycle processes, but also technology areas, mission/capability areas and leadership skills to ensure that systems engineers are well rounded in order to provide technical leadership to multi-disciplinary teams with role-diverse team members. When establishing a competency framework, careful consideration should be made toward which precise use case(s) will be supported by the framework. Not understanding the context and use of the competency framework can lead to a tremendous amount of KSA analysis that can be rendered useless or impractical. Identifying relevant and authoritative competency area and KSA sources for the competency framework is also critical, as there is no need to recreate data that has already been adequately developed by several other relevant and established industry and DoD organizations. In particular, the INCOSE, DAU SPRDE-SE, NASA and Navy SE competency models proved highly relevant to the execution of SE at SSC Atlantic. Due to SSC Atlantic's mission focus on IT and cyberspace, the NIST national cybersecurity workforce framework also proved highly useful in tailoring a SE competency framework.

When prioritizing competency areas and KSAs, each SE use case must be considered separately as each will likely emphasize different competency areas.

Competency areas such as stakeholder requirements definition, requirements analysis, architecture design, software engineering, acquisition, verification and system assurance require more emphasis at SSC Atlantic than others. In order to establish a complete set of KSAs at each competency development stage, a layered-cake approach should be taken, meaning that KSAs will be applicable to an increasingly narrowed sector of individuals. For example, Figure 30 shows how every SSC Atlantic employee needs leadership skills, members of the entire engineering department require "core" engineering skills, all systems engineers require a certain set of KSAs and then specific sub-roles or types of systems engineers require yet a separate set of KSAs. Each of these KSA sets is ultimately part of a systems engineer's competency development model. In order to establish systems engineering roles that can be well understood across the organization, one must examine the roles that will interact with the role of an SE in order to determine where KSAs will be shared across the roles or unique to one or the other.

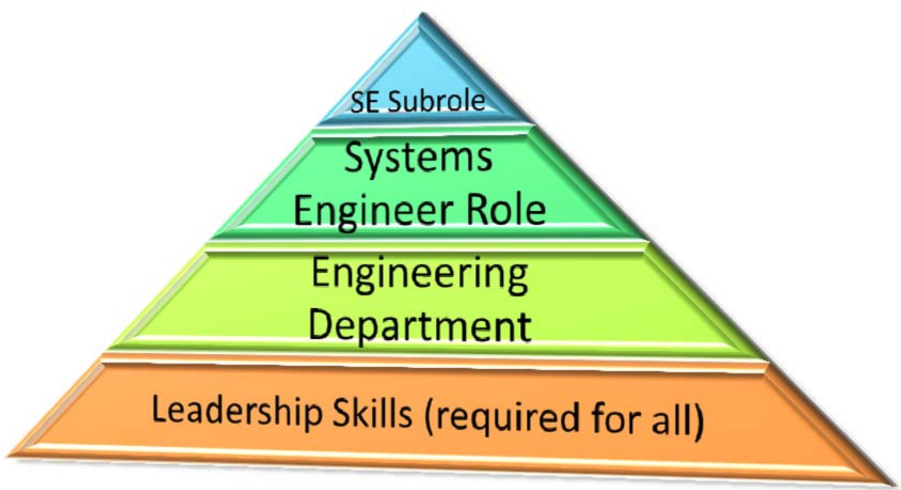

Figure 30. SSC Atlantic SE Competency Framework KSA Pyramid

Simply understanding which KSAs are most critical to developing systems engineers is insufficient. Analysis must be conducted to understand *how* these KSAs can and should be obtained. There are a number of ways to develop SE KSAs. The most common methods are through educational training (DAU, degrees or certifications), in-house-developed training courses/workshops, and OJT. DAU SPRDE-SE classes can be effective when providing systems engineers with basic knowledge and comprehension of

the SE life cycle processes—particularly in the areas of acquisition and risk management. Leadership skills can be developed through programs such as the Mid-Career Leadership and Mentorship Programs. OJT can be enhanced when coupled with targeted rotational opportunities and job shadowing opportunities. If approached systematically, immeasurable value can be obtained from developing in-house SE training that engages systems engineers at all levels of the workforce. GRCSE provides useful, tailorable recommendations on how to develop and assess SE curricula. When it comes to assessing the competency of systems engineers, care must be taken to choose an assessment process and associated assessment methodologies that are relatively thorough yet not overly cumbersome, time-consuming and costly.

C. FUTURE RESEARCH

While the topic of SE workforce development has been heavily studied over the last decade, there are still a large number of related areas that need additional research and analysis. Those interested in furthering the subject of SE workforce development should consider KSA configuration management methods, competency framework management tools, and long-term SE career progression models. As more DoD and industry SE organizations embrace the use of competency models, the need to vet feedback and refine competency model KSAs will grow. As competency areas and KSAs evolve, recommendations should also be made on how systems engineers are re-certified to keep up with the latest principles and trends. Competency framework and KSA management tools could significantly reduce the burden of managing the recommended KSAs of the SE organizations as well as the KSAs specifically obtained by individual systems engineers; yet, they largely do not exist today. Publications such as GRCSE v1.0 depict general career progression models for systems engineers; however, as SE competency frameworks become more stable and better understood by the greater SE workforce in the US, recommendations should be made as to specific, notional ways that systems engineers could and should pursue developing different KSAs and taking advantage of different opportunities over the course of their careers. Another area that could be further explored is the applicability of project management processes and IT topics from PMI and SFIA, respectively, to SE frameworks.

APPENDIX A. COMPETENCY MODEL USE CASE PROCESSES

The following competency model use case process models/figures were developed in collaboration with the SSC Atlantic Workforce Management Office in order to better understand the context and uses of CDM and KSA data.

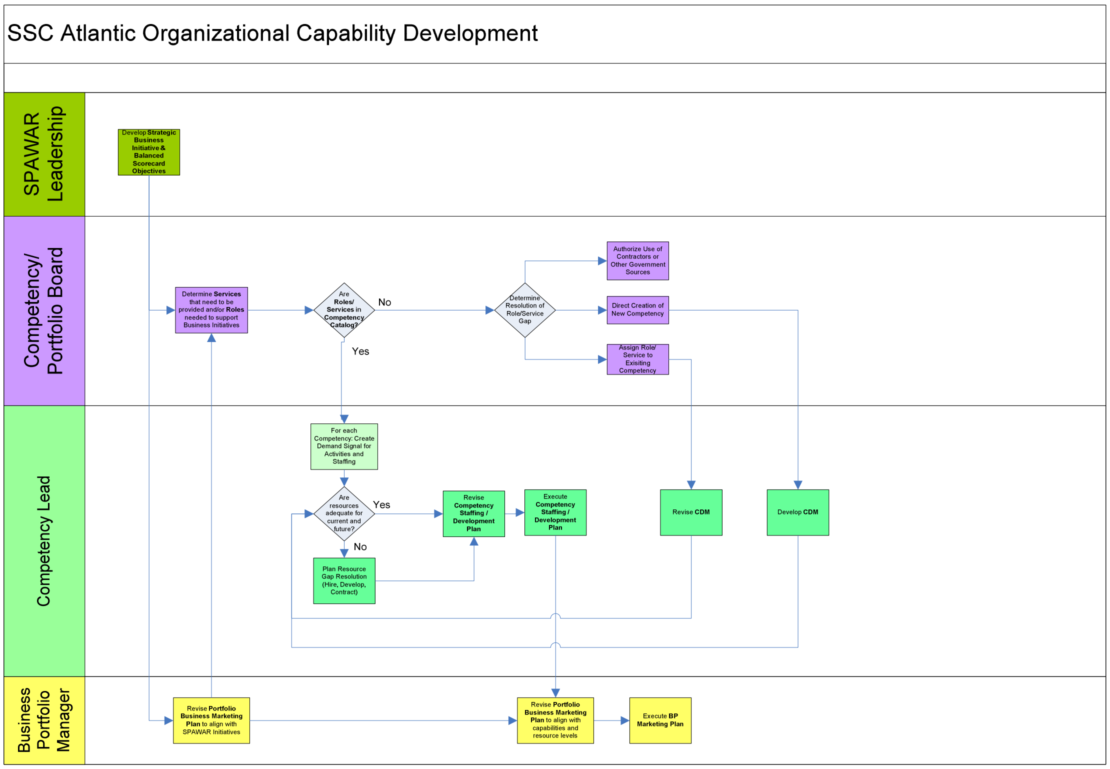

Figure 31. SSC Atlantic Organizational Capability Development

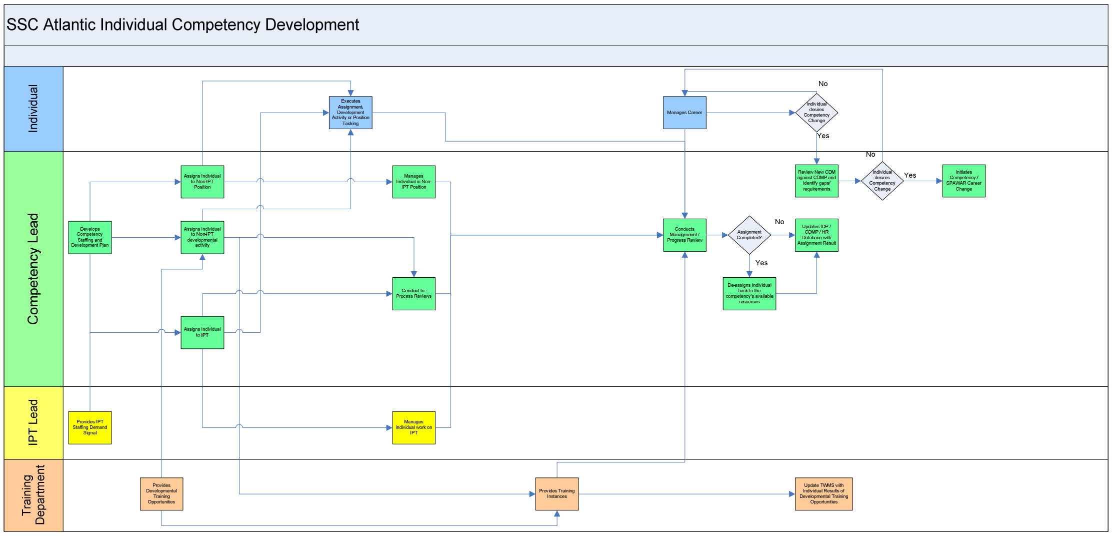

Figure 32. SSC Atlantic Individual Competency Development

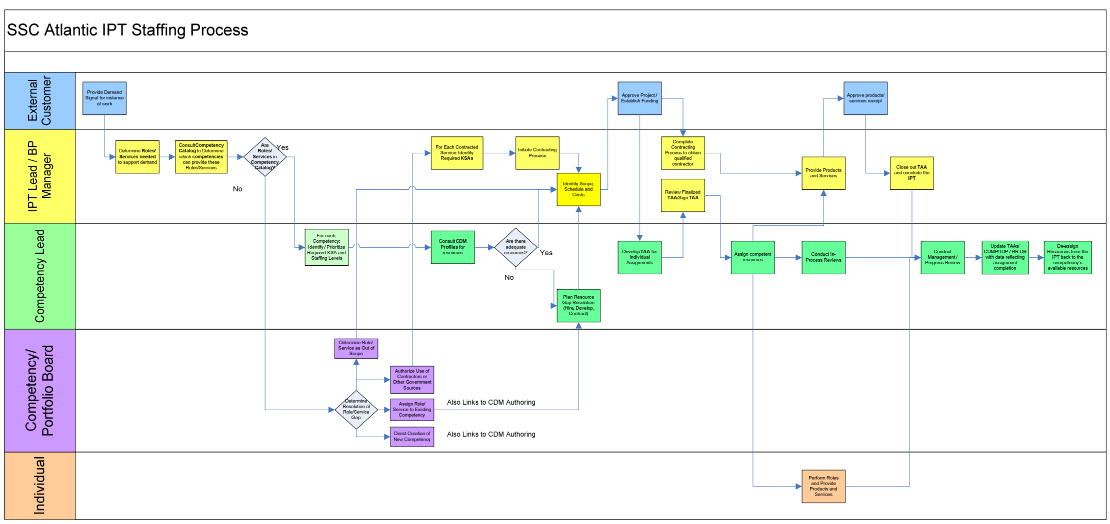

Figure 33. SSC Atlantic IPT Staffing Process

APPENDIX B. LEADERSHIP SKILLS

The following leadership skills and associated indicators were tailored from the 2011 version of Office of Personnel Management (OPM) leadership competency framework for use at SSC Atlantic.

Leadership Skill / Personal Attribute	Definition / Indicators	Stage
Accountability	Holds self and others accountable for measurable high-quality, timely, and cost-effective results.	Intermediate
Accountability	Focuses on results and measuring attainment of outcomes.	Intermediate
Accountability	Determines objectives, sets priorities, and delegates work.	Intermediate
Accountability	Accepts responsibility for mistakes.	Entry
Accountability	Complies with established control systems and rules.	Entry
Accountability	Completes projects within areas of specific responsibility in a timely manner and within budget.	Intermediate
Communication—Oral	Effectively and convincingly expresses information (for example, ideas or facts) to individuals or groups effectively, taking into account the audience and nature of the information (for example, technical, sensitive, controversial).	Intermediate
Communication—Oral	Expresses oral information (i.e. ideas or facts) clearly, effectively, and with appropriate command of the English language.	Entry
Communication—Oral	Listens effectively, including recognizing nonverbal cues. Clarifies information as needed. Seeks first to understand and then to be understood.	Intermediate
Communication—Oral	Uses verbal and non-verbal communication to enhance message	Entry
Communication—Oral	Facilitates an open exchange of ideas and fosters an atmosphere of open communication.	Intermediate
Communication—Oral	Ensures timely communication, sharing information and concerns.	Entry
Communication—Oral	Listens to others, attends to nonverbal cues, and responds appropriately.	Intermediate
Communication—Oral	Creates and utilizes media (i.e. transparencies, PowerPoint, etc.) for presentations.	Entry
Communication—Oral	Creates effective, organized presentations.	Intermediate
Communication—Oral	Makes clear and convincing oral presentations;	Intermediate
Communication—Oral	Listens to others, attends to nonverbal cues, and responds appropriately.	Intermediate
Communication—Oral	Performs the process of offering information or data for consideration or display.	Entry

Leadership Skill / Personal Attribute	Definition / Indicators	Stage
Communication - Written	Recognizes and uses correct English grammar, punctuation, and spelling.	Entry
Communication - Written	Communicates written information (for example, facts, ideas, or messages) in a succinct and organized manner.	Intermediate
Communication - Written	Produces written information, which may include technical material that is appropriate for the intended audience.	Intermediate
Conflict Management	Identifies and takes steps to prevent potential situations that could result in unpleasant confrontations.	Intermediate
Conflict Management	Manages and resolves conflicts, grievances, confrontations, or disagreements in a constructive manner to minimize negative personal impact.	Advanced
Conflict Management	Applies appropriate rules and protocol for resolving conflicts.	Advanced
Conflict Management	Formulates solutions to mitigate and resolve conflict.	Advanced
Continual Learning	Assesses and recognizes own strengths and weaknesses	Intermediate
Continual Learning	Pursues self-development	Entry
Continual Learning	Grasps the essence of new information.	Entry
Continual Learning	Masters new technical and business knowledge.	Entry
Continual Learning	Seeks feedback from others and opportunities to master new knowledge.	Entry
Continual Learning	Processes new information for later application.	Intermediate
Continual Learning	Applies information learned.	Entry
Creativity/ Innovation	Develops new insights into situations and applies innovative solutions to make organizational improvements.	Intermediate
Creativity/ Innovation	Creates a work environment that encourages creative thinking, new ideas, and innovation.	Intermediate
Creativity/ Innovation	Designs and implements new or cutting edge programs/processes.	Advanced
Creativity/ Innovation	Questions conventional approaches	Intermediate
Creativity/ Innovation	Develops new innovations, solutions, and insights.	Entry
Creativity/ Innovation	Evaluates conventional approaches.	Intermediate
Customer Service	Understands available products and services.	Intermediate
Customer Service	Readily readjusts priorities to respond to pressing and changing client demands.	Intermediate

Leadership Skill / Personal Attribute	Definition / Indicators	Stage
Customer Service	Works with clients and customers (that is, any individuals who use or receive the services or products that your work unit produces, including the general public, individuals who work in the agency, other agencies, or organizations outside the Government) to assess needs, provide information or assistance, resolve their problems, or satisfy their expectations;	Intermediate
Customer Service	Achieves quality end-products.	Intermediate
Customer Service	Is committed to providing quality products and services.	Intermediate
Decisiveness/ Problem Solving	Identifies and analyzes issues problems.	Entry
Decisiveness/ Problem Solving	Makes sound, well-informed, objective decisions.	Entry
Decisiveness/ Problem Solving	Understands the potential consequences and outcomes of different decisions.	Intermediate
Decisiveness/ Problem Solving	Makes effective and timely decisions, even when data is limited or solutions produce unpleasant consequences.	Advanced
Decisiveness/ Problem Solving	Is proactive and achievement oriented.	Intermediate
Decisiveness/ Problem Solving	Commits to action, even in uncertain situations, to accomplish organizational goals; causes change.	Advanced
Decisiveness/ Problem Solving	Determines accuracy and relevance of information	Intermediate
Decisiveness/ Problem Solving	Generates and evaluates alternatives to make recommendations.	Intermediate
Decisiveness/ Problem Solving	Conducts scholarly or scientific investigation or inquiry to solve a problem or inquiry to enhance understanding.	Intermediate
Decisiveness/ Problem Solving	Uses results to make appropriate recommendations or decisions.	Intermediate
Decisiveness/ Problem Solving	Creates alternative solutions to address a problem.	Intermediate
Entrepreneurship	Recognizes new opportunities.	Entry
Entrepreneurship	Positions the organization for future success by identifying new opportunities.	Intermediate
Entrepreneurship	Builds the organization by developing or improving products or services.	Advanced
Entrepreneurship	Takes calculated risks to accomplish organizational objectives.	Advanced
External Awareness/ Political Savvy	Identifies, understands, and keeps up to date on key national and international policies and economic, political, and social trends that affect the organization.	Advanced
External Awareness/ Political Savvy	Evaluates the impact of pertinent issues.	Advanced

Leadership Skill / Personal Attribute	Definition / Indicators	Stage
External Awareness/ Political Savvy	Understands near-term and long-range plans and determines how best to be positioned to achieve a competitive business advantage in a global economy.	Expert
External Awareness/ Political Savvy	Develops plans to achieve a competitive business advantage in a global economy.	Expert
External Awareness/ Political Savvy	Identifies the internal and external politics that impact the work of the organization.	Advanced
External Awareness/ Political Savvy	Approaches each problem or situation with a clear perception of organizational and political reality.	Advanced
External Awareness/ Political Savvy	Recognizes the impact of alternative courses of action.	Advanced
Financial Management	Applies understanding of organization's financial processes necessary to ensure appropriate funding levels.	Intermediate
Financial Management	Prepares, justifies, and/or administers the budget for the program area.	Intermediate
Financial Management	Uses cost-benefit approaches to set priorities.	Intermediate
Financial Management	Monitors expenditures and uses cost-benefit thinking to set priorities.	Intermediate
Financial Management	Identifies cost-effective approaches.	Intermediate
Financial Management	Applies procurement and contracting processes to programs and projects.	Intermediate
Financial Management	Evaluates procurement and contracting processes.	Advanced
Financial Management	Oversees procurement and contracting to achieve desired results.	Advanced
Flexibility/Resilience	Is open to change and new information	Entry
Flexibility/Resilience	Recognizes change in organizational conditions.	Intermediate
Flexibility/Resilience	Adapts behavior and work methods in response to new information, changing conditions, or unexpected obstacles.	Entry
Flexibility/Resilience	Effectively deals with ambiguity.	Intermediate
Flexibility/Resilience	Deals effectively with pressure.	Intermediate
Flexibility/Resilience	Maintains focus and intensity in ambiguous situations.	Advanced
Flexibility/Resilience	Maintains focus and intensity in pressure situations.	Intermediate
Flexibility/Resilience	Remains optimistic and persistent, even under adversity.	Intermediate
Flexibility/Resilience	Recovers quickly from setbacks.	Intermediate
Flexibility/Resilience	Effectively balances personal life and work.	Intermediate
Human Capital Management	Builds and manages workforce based on organizational goals, budget considerations, and staffing needs.	Advanced

Leadership Skill / Personal Attribute	Definition / Indicators	Stage
Human Capital Management	Ensures that employees are appropriately recruited, selected, appraised, and rewarded	Advanced
Human Capital Management	Recognizes performance problems.	Advanced
Human Capital Management	Takes action to address performance problems.	Advanced
Human Capital Management	Manages a multi-sector workforce and a variety of work situations.	Advanced
Information Management	Identifies a need for and knows where or how to gather information.	Intermediate
Information Management	Organizes and maintains information or information management systems.	Intermediate
Integrity/Honesty	Creates a culture that fosters high standards of ethics.	Advanced
Integrity/Honesty	Behaves in a fair and ethical manner toward others.	Entry
Integrity/Honesty	Demonstrates a sense of corporate responsibility.	Entry
Integrity/Honesty	Contributes to maintaining the integrity of the organization	Entry
Integrity/Honesty	Displays high standards of ethical conduct and understands the impact of violating these standards on an organization, self, and others.	Intermediate
Integrity/Honesty	Is trusted by others with tasks or information.	Intermediate
Interpersonal Skills	Shows understanding, friendliness, courtesy, tact, empathy, concern, and politeness to others.	Entry
Interpersonal Skills	Develops and maintains effective relationships with others.	Intermediate
Interpersonal Skills	Effectively deals with individuals who are difficult, hostile, or distressed	Advanced
Interpersonal Skills	Relates well to people from varied backgrounds and different situations.	Intermediate
Interpersonal Skills	Considers cultural diversity, race, gender, disabilities, and other individual differences to determine appropriate courses off action or responses.	Advanced
Leadership / Influence / Negotiation	Influences, motivates, and challenges others toward a common goal	Intermediate
Leadership / Influence / Negotiation	Adapts leadership styles to a variety of situations.	Advanced
Leadership / Influence / Negotiation	Persuades others to accept recommendations or cooperate.	Advanced
Leadership / Influence / Negotiation	Builds consensus through give and take.	Advanced

Leadership Skill / Personal Attribute	Definition / Indicators	Stage
Leadership / Influence / Negotiation	Gains cooperation from others to obtain information and accomplish goals.	Intermediate
Leadership / Influence / Negotiation	Works with others to reach an agreement	Intermediate
Leadership / Influence / Negotiation	Negotiates to find mutually acceptable solutions.	Intermediate
Partnering/ Collaborative Performance	Develops networks and builds alliances.	Advanced
Partnering/ Collaborative Performance	Engages in cross-functional activities.	Intermediate
Partnering/ Collaborative Performance	Collaborates across boundaries, and finds or achieves common ground with a widening range of stakeholders.	Advanced
Partnering/ Collaborative Performance	Utilizes contacts to build and strengthen internal support bases.	Intermediate
Partnering/ Collaborative Performance	Recognizes commonalities between individuals, groups, or stakeholder goals.	Intermediate
Self-Management	Systematically monitors one's own efforts and making appropriate modifications to ensure alignment with current or changing needs or goals.	Intermediate
Self-Management	Recognizes changes that warrant behavioral adaptations.	Intermediate
Self-Management	Sets well-defined and realistic personal goals.	Entry
Self-Management	Displays a high level of initiative, effort, and commitment towards completing assignments in a timely manner.	Entry
Self-Management	Works with minimal supervision.	Intermediate
Self-Management	Controls own goal-directed behavior without immediate external control.	Intermediate
Service Motivation	Creates and sustains an organizational culture which encourages others to provide the quality of service essential to high performance.	Advanced
Service Motivation	Enables others to acquire the tools and support they need to perform at a competent level.	Advanced
Service Motivation	Shows a commitment to public service.	Entry
Service Motivation	Aligns organizational objectives and practices with public interests.	Expert
Service Motivation	Ensures that actions meet public needs.	Advanced

Leadership Skill / Personal Attribute	Definition / Indicators	Stage
Service Motivation	Influences others toward a spirit of service and meaningful contributions to mission accomplishment.	Advanced
Strategic Thinking/Vision	Formulates effective strategies consistent with the business and competitive strategy of the organization in a global economy.	Expert
Strategic Thinking/Vision	Examines policy issues and strategic planning with a long-term perspective.	Expert
Strategic Thinking/Vision	Determines objectives and sets priorities.	Entry
Strategic Thinking/Vision	Anticipates potential threats or opportunities.	Intermediate
Strategic Thinking/Vision	Envisions positive organizational possibilities.	Advanced
Strategic Thinking/Vision	Develops the necessary procedures and operations to achieve organizational possibilities.	Advanced
Strategic Thinking/Vision	Develops appropriate measures to evaluate achievement.	Advanced
Strategic Thinking/Vision	Understands where the organization is headed and how to make a contribution	Intermediate
Strategic Thinking/Vision	Takes a long-term view and recognizes opportunities to help the organization accomplish its objectives or move toward the vision.	Advanced
Strategic Thinking/Vision	Builds a shared vision with others.	Advanced
Strategic Thinking/Vision	Influences others to translate vision into action.	Advanced
Team Building	Inspires and fosters team commitment, spirit, pride, and trust.	Intermediate
Team Building	Facilitates cooperation and motivates team members to accomplish group goals.	Intermediate
Team Building	Consistently develops and sustains cooperative working relationships.	Intermediate
Team Building	Encourages and facilitates cooperation and motivation within the organization and with customer groups to accomplish a common goal.	Advanced
Team Building	Fosters commitment, team spirit, pride, trust.	Advanced
Team Building	Develops capabilities in others through coaching, mentoring, rewarding, and guiding employees.	Advanced
Technical Expertise	Uses knowledge that is acquired through formal training or extensive on-the-job experience to perform one's job	Entry
Technical Expertise	Evaluates the technical sufficiency of work	Advanced
Technical Expertise	Works with, understands, and evaluates technical information related to the job	Intermediate

Leadership Skill / Personal Attribute	Definition / Indicators	Stage
Technical Expertise	Advises others on technical issues.	Expert
Technology Credibility	Applies principles, procedures, requirements, regulations, and policies related to specialized expertise.	Expert
Technology Credibility	Understands linkages between administrative competencies and mission needs.	Advanced
Technology Credibility	Addresses training and development needs.	Advanced
Technology Management	Maintains knowledge concerning technological developments.	Expert
Technology Management	Recognizes opportunities to integrate technology into the workplace.	Intermediate
Technology Management	Integrates technology into the workplace to achieve results and improve program effectiveness.	Advanced
Technology Management	Evaluates and plans for the impact of technological changes on the organization.	Advanced
Technology Management	Creates and maintains an accessible, secure technology system.	Advanced

Table 12. Recommended Leadership Skills for Systems Engineers (After Office of Personnel Management, 2011)

APPENDIX C. SSC ATLANTIC ENGINEERING DEPARTMENT ROLE DESCRIPTIONS

As of July 2013, the following eight primary roles have been defined within the SSC Atlantic Engineering Department (in addition to that of a systems engineer). An individual on an IPT may perform in one or more roles at any given time. These roles are subject to collapse into one another, expand or change in any way over time.

- **Technical Specialist—**Configure, implement, deliver, administer, troubleshoot and support information technology (IT) systems and services. Paramount requirement is knowledge of IT principles, concepts, and methods; Within their areas of expertise, technical specialists advise and contribute to the design, development and implementation of solutions while ensuring compliance with relevant domain policies, processes and standards. Early in the solution lifecycle, they ensure mission relevancy, support needs and feasibility analysis, decompose specifications, recommend alternatives and inform critical design decisions. Later in the lifecycle, technical specialists contribute domain expertise within tests, support installations, evaluate the solution against design or performance requirements and recommend necessary improvements or corrections.
- **Enterprise Architect—**Establishes and communicates mission and organizational needs; Develops and analyzes Concept of Operations; Defines capabilities, objectives, and measures of effectiveness (MOE)/measures of performance (MOP); Develops and evolves enterprise, System of Systems (SoS), and solution architectures; Conducts capability assessments and analysis; Develops, analyzes, and manages requirements; Identifies, defines and manages system interfaces; Assesses impacts of SoS and solution performance and upgrades; Conducts reviews and assessment focused on interoperability and management of risk; Manages strategic evolution of systems.
- **Software Professional—**Applies a systematic, disciplined, quantifiable approach to the design, development, coding, operation, and maintenance of software, and the study of these approaches.
- **Data Professional—**Responsible for the installation, configuration, and administration of database management systems or the management of data including architecture, analysis, and modeling.
- **Information Technology Service Management Specialist—**Leads an integrated discipline for developing, improving and assuring the quality of IT services and their management systems. Focuses on optimizing processes, personnel, technologies and organizational structures contributing to standardization and enforcement of enterprise behavior

around the customer's desired capabilities and bound by defined performance measures conformant with relevant standards and frameworks to reduce Total Cost of Ownership (TCO) and assure mission accomplishment

- **Tester—**Understands the intended purpose, operational context and concept of use of proposed systems. Plans and executes procedures to obtain, verify or provide data for the evaluation of progress in accomplishing developmental objectives, the performance, operational capability and suitability of systems, subsystems, component and equipment items, and their vulnerability and lethality. Verifies status of technical progress, verifies that design risks are minimized, substantiates achievement of contract technical performance, certifies readiness for initial operational testing (OT). Advises on testability of requirements and on risk involved in testing those requirements.
- **Information Assurance Professional—**Conduct scientific and engineering activities that protect and defend information and information systems by ensuring their availability, integrity and confidentiality. These activities require expertise for the development and deployment of technical measures to protect and defend networks, cyber systems, computers, and information from disruption, denial, degradation, or destruction and for the restoration of information and information systems. Provide IA engineering expertise to support Information Operations capabilities
- **Mission Specialist—**Uses a deep understanding of the context, characteristics and concepts of the customer's mission to define, guide and/or evaluate technical solutions that meet the operational needs of the user

APPENDIX D. SYSTEMS ENGINEER SUBROLE/SPECIALTY ROLE CARD SAMPLES

A. ROLE CARD SAMPLE: SYSTEMS ENGINEER—TECHNICAL MANAGEMENT

Specialty: <u>Technical Management</u> Identifies scope of engineering/technical tasks on an IPT. Determines the technical expertise and engineering processes required to support the IPT based on customer needs. Determine the roles/KSAs needed on an IPT and when to submit demand signals out to the appropriate competencies. Leads Technical Reviews (SETRs, etc.). Ensures proper review of engineering/technical deliverables produced by the project or IPT. Serves as the Engineering advisors for the IPT and adheres to latest Command Engineering initiatives. **<u>Note:</u>** The role of ***Systems Engineer—Technical Management*** may also be known as Lead Systems Engineer, Lead Systems Integrator, Technical Manager or Technical Lead
Typical Series: 0800 Series Engineers, 1515 Operations Research Analysts, 1550 Computer Scientists — **Typical DAWIA Career Path:** SPRDE-SE
Recommended Training: SE Planning, Intro to Requirements, Intro to Architecture, Systems Thinking, Intro to Complex Systems
Typical Work Products: Systems Engineering Plan, Requirements Doc/Matrix, Design Plans, Interface Design/Ctrl Document, Work Breakdown Structure & Schedule Inputs

Table 13. Systems Engineer—Technical Management Role Card Information

CDM Stage	Competency Area	Knowledge, Skill or Ability (KSA)
Entry	Stakeholder Requirements Definition	Assists in defining the business and mission need for systems that will provide services, capabilities or platforms to end users and other stakeholders.
Entry	Requirements Analysis	Analyzes, manages, and traces systems requirements.
Entry	Architecture Design	Identifies systems interfaces and interoperability concerns.
Intermediate	Systems Thinking	Demonstrates a broad understanding of the system context and environment
Intermediate	Architecture Design	Ability to develop a preliminary subsystem design based on existing best practices
Intermediate	Architecture Design	Ability to perform an Analysis of Alternatives (AoA)
Intermediate	Technical Planning	Understands the role of systems engineering planning as part of an overall project/program plan
Intermediate	Technical Planning	Knowledge of the command's global WBS
Intermediate	Technical Assessment	Develops design review and milestone decision approaches
Advanced	Technical Planning	Ability to develop a detailed Systems Engineering Plan
Expert	Technical Assessment	Able to chair variety of technical review boards (e.g. PDR, CDR, TRR)
Expert	Integration	Ability to identify and address issues associated with connecting multiple systems across organizational boundaries.

Table 14. Systems Engineer—Technical Management Key KSAs

B. ROLE CARD SAMPLE: SYSTEMS ENGINEER—PLATFORMS

<table>
<tr><td colspan="2">Specialty: <u>Platforms</u>
Provides engineering discipline in support of installing systems into a physical platform to ensure that environmental, mounting, heat, power, lighting, network infrastructure, safety, ergonomics and/or survivability requirements are met. Also ensures integration between system components. Primary process areas of interest include site surveys, Installation Design Plan and/or Technical Data Package development and review, BESEP creation, installation/integration oversight and PITCOs/SOVTs.

<u>Note</u>: Platform Systems Engineer may also be known as Platform Engineer or Project Engineer</td></tr>
<tr><td>Typical Series:
0800 Series Engineers</td><td>Typical DAWIA Career Path:
SPRDE-SE</td></tr>
<tr><td colspan="2">Recommended Training: Site Surveys, SE Planning, Shore Installation Process Handbook, Intro to Technical Data Packages or Installation Design Plans, Analysis of Alternatives</td></tr>
<tr><td colspan="2">Typical Work Products: Systems Engineering Plans, Base Electronic Systems Engineering Plans, Assessment Reports, Site Survey Reports, Requirements Doc/Matrix Design Plans, System Operation Verification & Test Docs</td></tr>
<tr><td colspan="2">Sub-specialties: Ashore (Command Centers, Air Traffic Control Facilities, Fuel Handling Facilities, Electronic Security Systems, etc.), Vehicular, Afloat, Expeditionary, Subsurface, etc.</td></tr>
</table>

Table 15. Systems Engineer—Platforms Role Card Information

CDM Stage	Competency Area	Knowledge, Skill or Ability (KSA)
Entry	Requirements Analysis	Analyzes, manages, and traces systems requirements.
Entry	Platforms	Ability to use a checklist to review an Installation Design Plan (IDP)
Entry	Platforms	Basic knowledge of computer, network and communications cabling and connectors
Intermediate	Stakeholder Requirements Definition	Assesses key conditions, constraints, conflicting requirements, and organizational issues, including safety and security factors.
Intermediate	Platforms	Knowledge/skill in shore installation/upgrade processes (e.g., the Shore Installation Process Handbook), including design, development, acquisition, documentation, CM, scheduling, resource management, site surveys, installations, system cutover, System Operational Verification and Testing (SOVT) & system turnover
Intermediate	Architecture Design	Ability to perform an Analysis of Alternatives (AoA)
Advanced	Architecture Design	Specify power supply and heating, ventilation, and air conditioning (HVAC) requirements and configuration based on system performance expectations and design specifications
Advanced	System Assurance	Design and develop secure interfaces specifications between interconnected systems
Advanced	Requirements Analysis	Recommends changes to systems requirements to align with government policy, and addresses future integration and interoperability challenges across programs or the enterprise.
Expert	Integration	Ability to define SSC Atlantic product & platform integration policies

Table 16. Systems Engineer—Platforms Key KSAs

APPENDIX E. RECOMMENDED WORKFORCE DEVELOPMENT METHODS FOR EACH SYSTEMS ENGINEER KSA

The following table displays each systems engineer KSA by competency vector, competency area and stage. The recommended development method for each KSA and the associated justification are shown in the far right columns of the table.

Competency Vector	Competency Area	KSA	Stage	Recom-mended Method	Justification / Comments
Activity	GENERAL	Basic knowledge of technical and technical mgt processes	Entry	DAU	well covered in DAU SPRDE-SE curriculum
Activity	GENERAL	Knowledge of engineering/technical artifacts required by SSC Atlantic	Entry	in-house	unique to SSC Atlantic
Activity	GENERAL	Ability to review engineering/technical artifacts for completeness and quality	Intermediate	in-house	unique to SSC Atlantic
Activity	1.0 TECHNICAL BASIS FOR COST	Knowledge of SPAWAR accounting and financial systems	Entry	in-house	unique to SSC Atlantic
Activity	1.0 TECHNICAL BASIS FOR COST	Ability to contribute to timely and accurate full cost budget information (such as labor, procurement, travel estimates) to project managers when requested	Entry	in-house	unique to SSC Atlantic cost estimation methods/tools
Activity	1.0 TECHNICAL BASIS FOR COST	Ability to perform cost estimating on technical work products	Entry	OJT	experiential developmental activities required
Activity	1.0 TECHNICAL BASIS FOR COST	Ability to use Work Breakdown Structure (WBS) as a tool for tracking actual vs. estimated costs and use this information to revise cost models appropriately	Entry	DAU	well covered in DAU SPRDE-SE curriculum

Competency Vector	Competency Area	KSA	Stage	Recom-mended Method	Justification / Comments
Activity	2.0 MODELING & SIMULATION	Knowledge of decision support tools, models, or simulations that are applicable to your job.	Entry	in-house	unique to SSC Atlantic models, use cases
Activity	3.0 SAFETY ASSURANCE	Understand and comply with safety strategies, policies, and standards	Entry	external vendor	Not covered by DAU
Activity	3.0 SAFETY ASSURANCE	Understands the relationship between reliability, availability, maintainability and safety	Intermediate	degree/ cert	academia provides ample RAM material
Activity	4.0 STAKEHOLDER REQUIREMENTS DEFINITION	Able to identify major stakeholders	Entry	in-house	stakeholder groups somewhat specific to SSC Atlantic
Activity	4.0 STAKEHOLDER REQUIREMENTS DEFINITION	Understand the importance of requirements traceability	Entry	DAU	well covered in DAU SPRDE-SE curriculum
Activity	4.0 STAKEHOLDER REQUIREMENTS DEFINITION	Can support the elicitation of requirements from stakeholders	Intermediate	OJT	experiential developmental activities required
Activity	5.0 REQUIREMENTS ANALYSIS	Understands that there are different types of requirements e.g. functional, non-functional, business etc.	Entry	DAU	well covered in DAU SPRDE-SE curriculum
Activity	5.0 REQUIREMENTS ANALYSIS	Understands the importance of managing requirements throughout the lifecycle	Entry	DAU	well covered in DAU SPRDE-SE curriculum

Competency Vector	Competency Area	KSA	Stage	Recommended Method	Justification / Comments
Activity	5.0 REQUIREMENTS ANALYSIS	Understands the need for quality requirements (achievable, verifiable, unambiguous, necessary and sufficient, complete, expressed as a need, consistent, and appropriate)	Entry	DAU	well covered in DAU SPRDE-SE curriculum
Activity	5.0 REQUIREMENTS ANALYSIS	Contribute to decomposition of requirements	Entry	in-house	requires tailored exercises; could also be done through OJT or degree/cert
Activity	5.0 REQUIREMENTS ANALYSIS	Contribute to development of specification documents	Entry	OJT	difficult to train
Activity	5.0 REQUIREMENTS ANALYSIS	Understands the relationship between design and requirements	Intermediate	DAU	could also leverage SE degree/cert
Activity	5.0 REQUIREMENTS ANALYSIS	Ability to identify and analyze requirements	Intermediate	in-house	requires tailored exercises; could also be done through OJT or degree/cert
Activity	6.0 ARCHITECTURE DESIGN	Basic knowledge of the different types of architecture	Entry	in-house	unique to SSC Atlantic application of enterprise architecture discipline
Activity	6.0 ARCHITECTURE DESIGN	Identifies systems interfaces and interoperability concerns.	Entry	in-house	basic ability could be covered by in-house training; otherwise - OJT
Activity	6.0 ARCHITECTURE DESIGN	Understands the need to explore alternative and innovative ways of satisfying the system need	Entry	in-house	could also leverage SE degree/cert

Competency Vector	Competency Area	KSA	Stage	Recom-mended Method	Justification / Comments
Activity	6.0 ARCHITECTURE DESIGN	Knowledge of the principles of architectural design and its role within the lifecycle	Entry	DAU	well covered in DAU SPRDE-SE curriculum
Activity	6.0 ARCHITECTURE DESIGN	Identify the basic elements/sections of an Technical Data Package (TDP)	Entry	in-house	unique to SSC Atlantic approach to TDPs
Activity	10.0 VALIDATION	Understands the purpose of validation	Entry	DAU	well covered in DAU SPRDE-SE curriculum
Activity	10.0 VALIDATION	Understand structure and basic elements of a SOVT document	Entry	in-house	SOVT is a tailored verification & validation concept
Activity	11.0 TRANSITION	Aware of the type of activities required for transition to operation	Entry	DAU	well covered in DAU SPRDE-SE curriculum
Activity	12.0 SYSTEM ASSURANCE	Knowledge of Risk Management Framework (RMF)	Entry	TBD	RMF is in process of being released
Activity	12.0 SYSTEM ASSURANCE	Knowledge of information assurance principles and tenets (confidentiality, integrity, availability, authentication, non-repudiation).	Entry	DAU	could also leverage SE degree/cert
Activity	15.0 TECHNICAL PLANNING	Basic knowledge of technical disciplines/specialties applicable to SSC Atlantic	Entry	in-house	unique to SSC Atlantic
Activity	15.0 TECHNICAL PLANNING	Knowledge of the command's global WBS	Intermediate	in-house	unique to SSC Atlantic
Activity	15.0 TECHNICAL PLANNING	Able to tailor systems engineering processes to meet the needs of a specific project/program	Intermediate	OJT	experiential developmental activities required

Competency Vector	Competency Area	KSA	Stage	Recom-mended Method	Justification / Comments
Activity	15.0 TECHNICAL PLAN NING	Understands the importance of planning, monitoring and controlling systems engineering activities	Entry	DAU	well covered in DAU SPRDE-SE curriculum
Activity	15.0 TECHNICAL PLAN NING	Aware that common technical processes need to be planned	Entry	DAU	well covered in DAU SPRDE-SE curriculum
Activity	16.0 TECHNICAL ASSES SMENT	Able to (for a subsystem or simple project) monitor progress against plans	Intermediate	OJT	experiential developmental activities required
Activity	16.0 TECHNICAL ASSES SMENT	Identifies continuous process improvements that enhance processes, products, and service quality.	Entry	in-house	In-house CPI training capability exists
Activity	16.0 TECHNICAL ASSES SMENT	Aware of review types and their purposes	Entry	DAU	well covered in DAU SPRDE-SE curriculum; however, there are SSC Atlantic unique review types as well
Activity	16.0 TECHNICAL ASSES SMENT	Aware of activities to prepare for technical assessments	Entry	DAU	well covered in DAU SPRDE-SE curriculum; however, there are SSC Atlantic unique review types as well
Activity	17.0 CONFIGURATION MANAGEMENT	Knowledge and basic ability to perform configuration management activities	Entry	DAU	knowledge can come from DAU, but ability through in-house /OJT
Activity	17.0 CONFIGURATION MANAGEMENT	Aware of configuration change control	Entry	DAU	well covered in DAU SPRDE-SE

Competency Vector	Competency Area	KSA	Stage	Recom-mended Method	Justification / Comments
Activity	18.0 REQUIREMENTS MANAGEMENT	Participate in (for a subsystem or simple project) documenting requirements in the proper format.	Intermediate	in-house	unique to SSC Atlantic requirements documentation approach
Activity	18.0 REQUIREMENTS MANAGEMENT	Knowledge of the Engineering Change Proposal (ECP) review process	Entry	in-house	unique to SSC Atlantic ECR approach
Activity	18.0 REQUIREMENTS MANAGEMENT	Knowledge of requirements management process.	Entry	DAU	well covered in DAU SPRDE-SE
Activity	19.0 RISK MANAGEMENT	Knowledge of and the ability to contribute to identification of risk, risk analysis, and risk monitoring	Entry	DAU	risk mgt well covered in DAU SPRDE-SE
Activity	19.0 RISK MANAGEMENT	Assists in executing the risk mitigation plan to ensure successful project and program completion.	Entry	OJT	experiential developmental activities required
Activity	20.0 TECHNICAL DATA	Ability to document and present lessons learned	Entry	OJT	experiential developmental activities required
Activity	21.0 INTERFACE MANAGEMENT	Understands the need for interface management and its impact on the integrity of the system solution	Entry	DAU	well covered in DAU SPRDE-SE
Activity	22.0 SOFTWARE ENGINEERING	Basic understanding of software engineering principles	Entry	DAU	well covered in DAU SPRDE-SE
Activity	23.0 ACQUISITION	Ability to develop a Performance Work Statement (PWS) / Statement of Objectives (SOO)	Intermediate	in-house	unique to SSC Atlantic PWS/SOO standards

Competency Vector	Competency Area	KSA	Stage	Recom-mended Method	Justification / Comments
Activity	23.0 ACQUISITION	Provides information for the Performance Work Statement (PWS) / Statement of Objectives (SOO)	Entry	OJT	experiential developmental activities required
Activity	25.0 SYSTEM OF SYSTEMS	Understands that SoS capability needs impact the system development	Entry	OJT	experiential developmental activities required
Activity	30.0 SYSTEMS THINKING	Able to describe the systems engineering lifecycle processes that are in place on their program	Intermediate	DAU	well covered in DAU SPRDE-SE
Activity	30.0 SYSTEMS THINKING	Able to define system boundaries and external interfaces	Intermediate	OJT	experiential developmental activities required
Activity	30.0 SYSTEMS THINKING	Aware of the influence the system has on the enterprise	Entry	OJT	experiential developmental activities required
Activity	Data Engineering	Awareness of data management and data storage concepts	Entry	external vendor	training classes exist, but outside of SPRDE-SE
Activity	Enterprise Architecture	Knowledge and understanding of the purpose and value of using architectures for requirements documentation; systems planning and investment decisions	Entry	in-house	not well stressed in SPRDE-SE
Activity	Enterprise Architecture	Knowledge of DoD enterprise architecture principles and reference models	Intermediate	in-house	could also leverage SE degree/cert

Competency Vector	Competency Area	KSA	Stage	Recom-mended Method	Justification / Comments
Technology	Communications	Basic knowledge of the characteristics of different communications systems	Entry	in-house	could also leverage external vendor
Technology	IT SERVICE MANAGEMENT	Awareness DoD and DON ITSM policies, guidance and core references	Entry	in-house	SSC Atlantic maintains basic ITSM training capability
Technology	Networks	Knowledge of computer networking fundamentals	Entry	degree/ cert	could also leverage external vendor
Mission	GENERAL	Basic understanding of all Mission Areas / Domains	Entry	in-house	could also leverage SE degree/cert for more in-depth knowledge
Core to Systems Engineer					
Activity	1.0 TECHNICAL BASIS FOR COST	Ability to contribute to a Project Management Plan (PMP)	Intermediate	in-house	Would show how a SE contributes to a PMP at SSC Atlantic
Activity	1.0 TECHNICAL BASIS FOR COST	Ability to Review and approve cost estimates for subsystem elements.	Intermediate	OJT	experiential developmental activities required
Activity	5.0 REQUIREMENTS ANALYSIS	Understands the characteristics of quality requirements	Intermediate	DAU	well covered in SPRDE-SE
Activity	5.0 REQUIREMENTS ANALYSIS	Prioritizes requirements for system upgrades and future enhancements with the sponsor/customers, key	Advanced	OJT	experiential developmental activities required

Competency Vector	Competency Area	KSA	Stage	Recommended Method	Justification / Comments
		stakeholders, and end users			
Activity	6.0 ARCHITECTURE DESIGN	Facilitates agreements among multiple stakeholders to resolve system interfaces and interoperability concerns.	expert	OJT	experiential developmental activities required
Activity	16.0 TECHNICAL ASSESSMENT	Executes continuous process improvements that enhance processes, products, and service quality.	Intermediate	in-house	In-house CPI training capability exists
Activity	17.0 CONFIGURATION MANAGEMENT	Basic ability to use configuration management tools for configuration management	Entry	in-house	unique to SSC Atlantic-specific CM tool(s)
Activity	19.0 RISK MANAGEMENT	Knowledge of and the ability to contribute to development of risk mitigation/contingency action plans	Entry	in-house	Must know how to do risk mgt IAW command policy/tool
Activity	19.0 RISK MANAGEMENT	Able to perform risk analysis	Intermediate	DAU	well covered in SPRDE-SE
Activity	23.0 ACQUISITION	Serve on Source Evaluation Board (SEB) or as a Contracting Officer's Representative (COR) and have experience with development and implementation of contracts, procurement of major hardware or software	Intermediate	OJT	experiential developmental activities required

Competency Vector	Competency Area	KSA	Stage	Recom-mended Method	Justification / Comments
Activity	30.0 SYSTEMS THINKING	Able to define technical problem scope	Intermediate	in-house	unique to SSC Atlantic technical scoping use cases

Table 17. Recommended Development Method for Each Systems Engineer KSA

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